Gordon, Lisa Perras

From:	Mary Lou Addor - Lou [Mary_Addor@ncsu.edu]
Sent:	Monday, October 28, 2013 7:33 PM
To:	eflows-sab@lists.ncmail.net
Subject:	[eflows-sab] EFSAB Final Report to DENR
Attachments:	EFSAB Report FINAL 2013-10-28.pdf; EFSAB Report FINAL 10282013.docx; ATT00001.txt

Good evening and Congratulations!

You all have arrived at your destination.

Attached is the final EFSAB report for presentation to Tom Reeder.

Chris, Tom, Fred, Linda, and Jim took us through the final stretch. Many thanks to them for facilitating the closing details.

I am asking Fred to distribute the final copy to Tom Reeder this Thursday.

More details will be forthcoming regarding Dec 3 in a future email - so please keep that afternoon on your calendar.

Best to each of you until then,

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Recommendations for Estimating Flows to Maintain Ecological Integrity in Streams and Rivers in North Carolina

Submitted to the
North Carolina Department of Environment and Natural Resources
by the
North Carolina Ecological Flows Science Advisory Board

November 2013

DEDICATION

Photo courtesy of Mark Cantrell

The Ecological Flows Science Advisory Board dedicates this report to the memory of Steve Reed in appreciation of his many contributions to the state of North Carolina through his work at the Division of Water Resources.

For more than three decades, Steve led efforts to establish ecological flows in North Carolina, contributing to the science and practice, while leaving a deep impression on all he met with his kindness and professionalism. Steve died suddenly in July, 2012 before the completion of this effort, but his spirit continued to inspire the work behind this report and will inspire the future work of others.

Cover photos courtesy of Vann Stancil

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EXECUTIVE SUMMARY

The Ecological Flows Science Advisory Board (EFSAB) was created to assist the Department of Environment and Natural Resources (DENR) with developing a scientifically defensible approach to establishing flows that protect the ecological integrity of streams and rivers in North Carolina as required under Session Law 2010-143. The EFSAB was tasked with reviewing published and unpublished studies that characterize the ecology of North Carolina rivers, relating ecological conditions to flow alteration, and identifying a scientifically defensible approach to establishing flow requirements for the maintenance of ecological integrity. Per Session Law 2010-143, the EFSAB included representatives from the state (the N.C. Division of Water Resources, the N.C. Division of Water Quality, the N.C. Wildlife Resources Commission, the N.C. Division of Marine Fisheries, and the N.C. Natural Heritage Program), the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and individuals with expertise in aquatic ecology and habitats from organizations representing agriculture, forestry, manufacturing, electric public utilities, non-governmental organizations, local governments, and other individuals and organizations.

The EFSAB elicited input from a wide variety of state, federal, and local agencies as well as academic and non-governmental organizations in reviewing existing strategies for determining ecological flows and in conducting new analyses within the State. The EFSAB focused on reviewing ecological flow literature, hearing and discussing presentations from ecological flow experts, and reviewing flow-ecology research conducted in North Carolina. In addition, the EFSAB worked through informal subcommittees to analyze flow-ecology relations using data (fish and benthic macroinvertebrate) specific to North Carolina streams and to address flow and ecology issues unique to streams in the coastal plain. The work of these subcommittees helped the EFSAB make recommendations that were more specific to North Carolina streams than was possible by relying solely on recommendations obtained from literature review.

Based on the review of existing work and the detailed analyses conducted by the subcommittees, the EFSAB recommends that DENR use a two-part strategy to establish ecological flows, determine if future conditions support these flows, and assess whether additional review and studies are warranted:

1. **Percentage-of-flow strategy:** establish ecological flows on the basis of 80-90% flow-by (i.e., 80-90% of ambient modeled flow remains in the stream) in combination with a critical low-flow component that identifies when additional actions may be needed to protect ecological integrity. The critical low-flow component is intended to minimize increases in the magnitude and duration of extreme low flows during drought conditions. If the basinwide hydrologic models and critical low-flow component indicate that there is not sufficient water available to meet essential water uses and ecological flows at a given location, further review by DENR is recommended. This strategy of establishing ecological flows is similar to approached used by other states and countries. The EFSAB has not recommended a specific value for the low-flow component, but recommends that DENR establish these values based on an analysis of typical and extreme low-flow conditions in North Carolina.

2. **Biological-response strategy:** evaluate the effects of ecological flows using models that relate changes in fish and invertebrate communities to current and future flows derived from the percentage-of-flow strategy. The biological-response strategy directly

links the statewide fish and invertebrate data collected by DENR with flow data derived from basinwide hydrologic models to predict biological changes. The EFSAB recommends that DENR use a 5-10% reduction in biological condition—using (A) Shannon-Weaver Diversity Index for fish and (B) number of taxa in the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) for invertebrates—as a threshold for initiating further review by DENR.

The EFSAB recognizes that the science underlying these recommendations will evolve as more research addresses flow-ecology issues at additional spatial and temporal scales. The EFSAB understands that the hydrologic and biologic models on which our recommendations are based may need to be revised as changes in climate and land cover alter patterns in precipitation, temperature (air and water), and runoff across the state. The flow and biological criteria recommended by the EFSAB will need to be reevaluated to determine their efficacy throughout the state and through time. Gaps in available hydrologic and biologic data (headwater, coastal plain and large rivers) will need to be addressed in order to provide a more complete representation of flow effects on biological integrity within the state. Consequently, the EFSAB recommends that DENR take an adaptive management approach to establishing flows that protect the ecological integrity of North Carolina streams. This approach should address the following issues:

1. Collect additional hydrologic and biologic data in headwater, coastal plain and large rivers that are currently underrepresented in DENR datasets. These data will help determine if these streams fit into current models and assumptions.

2. Adopt, design, and develop strategies to:

    a. Validate the efficacy of ecological thresholds and adjust as necessary. Validation should be informed by new data and/or research.

    b. Track the impact of flow changes when and where they occur.

    c. Modify characterizations, target flows, and thresholds based on new data, changing conditions (e.g., land cover, precipitation, hydrology) and lessons learned.

    d. Georeference nodes in the OASIS hydrologic model to facilitate analysis.

The recommendations of the EFSAB represent a starting point for developing ecological flows that protect the integrity of North Carolina streams. By adopting an adaptive management approach, DENR can ensure that ecological integrity is protected through the refinement and improvement of the recommendations of the EFSAB over time.

GLOSSARY

7Q10 – the lowest average flow that occurs for seven consecutive days with a recurrence probability of once every 10 years. The 7Q10 value is typically used for determining assimilative capacity for receiving streams when permitting wastewater discharges. Flows equal to the 7Q10 generally occur during drought.

Annual 30-day Minimum Flow – the lowest 30-day mean flow calculated as a moving average for every 30-day period that is completely within the water year.

BEC – Biological Environmental Classification analysis performed by RTI International.

CHEOPS (Computer Hydro-Electric Operations and Planning Software) – simulation package developed by HDR, Inc. to evaluate the costs and benefits associated with a wide range of changes to a hydropower system. CHEOPS was developed for and is currently used to model flows in the Catawba River.

Condition Class – a classification system in which sampling sites are divided into classes on the basis of an ecological attribute or collection of attributes. Classes are ordered by the amount of change in the ecological attribute that occurs along a disturbance gradient that ranges from undisturbed (Excellent condition class) to highly disturbed condition (Poor condition class).

cfs – cubic feet per second (1 cfs = 0.646 million gallon per day).

ecological deficit (ecodeficit) – the total difference between the altered and unaltered flow duration curves, whenever the altered curve falls below the unaltered curve.

ecological flow – "stream flow necessary to protect ecological integrity" [as defined by General Statute 143-355(o)(1)].

ecological integrity – "the ability of an aquatic system to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to prevailing ecological conditions and, when subject to disruption, to recover and continue to provide the natural goods and services that normally accrue from the system" [as defined by General Statute 143-355(o)(1)].

ELOHA (Ecological Limits of Hydrologic Alteration) – a step-wise flow determination process that includes establishing a hydrologic foundation, classifying rivers, and determining flow-ecology relationships before entering a social process to develop flow regime standards (see Poff et al. 2009).

EPT – the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies).

EPTr (EPT richness) – total number of taxa collected at a site from the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies).

flow duration curve – a cumulative curve that shows the percent of time specified discharges were equaled or exceeded during a given period.

guild – a grouping of species, or species life stages, based on similar habitat requirements.

Index B – habitat metric used during time series analysis, a component of PHABSIM (see below), calculated by averaging all weighted usable area (see WUA) habitat values between the 10th and 90th percentiles on a monthly or seasonal basis for a flow record. Used to compare different flow regimes.

Invertebrate – animals that lack a backbone such as insects, worms, mussels, clams, snails, and crayfish.

Monthly median – In general hydrologic terms the middle flow value for the rank ordered flows for all years of a month (i.e. the 50th percentile).

mgd – million gallons per day (1 mgd = 1.547 cubic feet per second).

NWIS (National Water Information System) – US Geological Survey (USGS) and US Environmental Protection Agency (EPA) work together to provide scientists and policy-makers an easier way to discover and acquire water quality data from their large water quality databases and share water monitoring data via a common format and terminology. A Water Quality Portal is available at www.waterqualitydata.us for downloading monitoring location information and associated water quality results that are automatically linked and integrated from both USGS and US EPA databases.

OASIS (Operational Analysis and Simulation of Integrated Systems) – generalized program for modeling the operations of water resources systems, developed by HydroLogics, Inc., that routes water through a system represented by nodes and arcs. OASIS is the hydrologic model currently used by the Division of Water Resources to model flow and water use in the major river basins.

ORW (Outstanding Resource Water) – a supplemental water quality classification designated by the EMC for special or unique surface waters in NC having excellent water quality and being of exceptional state or national ecological or recreational significance.

p-value – a measure of the probability that an observed value (e.g., slope or intercept in a regression) is the result of random chance. Low p-values (<0.05) are generally considered to be statistically significant.

PHABSIM (Physical Habitat Simulation) – a specific model designed to calculate an index to the amount of microhabitat available for different organisms and life stages at different flow levels, incorporating two major analytical components: stream hydraulics and organism/life stage-specific habitat requirements.

PNV (potential natural vegetation) – the types of vegetation that would exist under most favorable conditions in the conterminous United States as proposed by A.W. Kuchler (1964).

Prevailing ecological conditions – "the ecological conditions determined by reference to the applicable period of record of the United States Geological Survey stream gauge data, including data reflecting the ecological conditions that exist after the construction and operation of existing flow modification devices, such as dams, but excluding data collected when stream flow is temporarily affected by in-stream construction activity" [from General Statute 143-355(o)(1)].

Q – volumetric flow rate, typically expressed in cubic feet per second.

Quantile Regression – a type of regression analysis that estimates either the conditional median or other quantiles (e.g., 80th or 90th) of the response variable. Quantile regression has been used in ecological studies to uncover predictive relationships between variables where the relationship is weak or obscured by other variables.

SE (standard error) – a statistical term that measures how accurately a sample represents the underlying population. The smaller the standard error, the more representative the sample is of the population.

September Median – the monthly median flow for September (see monthly median). The September median flow has sometimes been used as a minimum flow in the Southeast because September is typically the month with the lowest monthly median flow.

Shannon-Weaver Diversity Index – a quantitative measure that reflects how many different types (such as species) there are in a dataset, and simultaneously takes into account how evenly the basic entities (such as individuals) are distributed among those types.

Tennant method – a hydrologic standard setting approach for minimum flows based on percentage of mean annual flow that varies by month.

Trimmed hydrology dataset – a hydrology dataset that excludes a designated percentage of data at the upper and/or lower ends of the cumulative frequency distribution. For example, a dataset that excludes the highest and lowest 10% contains the central 80% of the data.

WaterFALL™ (Watershed Flow and ALLocation) – watershed modeling tool developed by the RTI International using National Hydrography Dataset (NHDPlus) hydrologic catchments to investigate water availability and allocation at multiple geographic scales.

WUA (weighted usable area) – an amount of habitat determined by PHABSIM, often represented as square feet of habitat per thousand feet of stream (see PHABSIM).

ACRONYMS

APNEP – The Albemarle Pamlico National Estuary Partnership

AWWA – American Water Works Association

BEC – Biological Environmental Classification (see glossary for definition)

CEFWG – Coastal Ecological Flows Working Group

CFS – cubic feet per second

CHEOPS – Computer Hydro-Electric Operations and Planning Software (see glossary for definition)

CHPP – Coastal Habitat Protection Plan

DENR – Department of Environment and Natural Resources

DMF – Division of Marine Fisheries

DO – dissolved oxygen

DWQ – Division of Water Quality (as of 2013, merged with DWR)

DWR – Division of Water Resources

ECU – East Carolina University

EDF – Environmental Defense Fund

EEP – Ecosystem Enhancement Program

EFS – Environmental Flow Specialists, Inc.

EFSAB – Ecological Flows Science Advisory Board

ELOHA – Ecological Limits of Hydrologic Alteration (see glossary for definition)

EMC – Environmental Management Commission

EPT – insect orders of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) (see glossary for definition)

ERC – Environmental Review Commission

GIS – Geographic Information System

G.S. – General Statute

MAF – mean annual flow

MFC – Marine Fisheries Commission

MGD – million gallons per day

NCDA&CS – North Carolina Department of Agricultural and Consumer Services

NCFA – North Carolina Forestry Association

NCFS – North Carolina Forest Service

NHD+ – National Hydrography Dataset Plus

NHP – Natural Heritage Program

NMFS – National Marine Fisheries Service

NOAA – National Oceanic and Atmospheric Administration

NWIS – National Water Information System (see glossary for definition)

OASIS – Operational Analysis and Simulation of Integrated Systems (see glossary for definition)

ORW – Outstanding Resource Waters (see glossary for definition)

PHABSIM – Physical Habitat Simulation (see glossary for definition)

RTI – Research Triangle Institute

SALCC – South Atlantic Landscape Conservation Cooperative

SARP – Southeastern Aquatic Resources Partnership

SAS – Statistical Analysis System

SE – standard error

SG – Sea Grant Program

TNC – The Nature Conservancy

UNC IMS – University of North Carolina Institute of Marine Sciences

USFWS – United States Fish and Wildlife Service

USGS – United States Geological Survey

WaterFALL™ – Watershed Flow and ALLocation (see glossary for definition)

WRC – North Carolina Wildlife Resources Commission

WRRI – Water Resources Research Institute

WUA – weighted usable area (see glossary for definition)

1 PREFACE

1.1 The Department (DENR) and Division (DWR)

The North Carolina Department of Environment and Natural Resources (DENR) is the lead stewardship agency for the preservation and protection of North Carolina's natural resources. Hereinafter referred to as the Department or DENR, the organization administers regulatory programs designed to protect air quality, water quality, and the public's health. The Department, through its Division of Water Resources (DWR), specifically administers water resource planning for the state and has been tasked with convening and providing staff support to the Ecological Flows Science Advisory Board (EFSAB).

1.2 Legislative Background

Session Law 2010-143 (Appendix A) amended portions of General Statute (G.S.) 143, Article 38 which deals with water resources. Specifically, the Session Law added language to G.S. 143-355 requiring DENR to develop basinwide hydrologic models for each of the 17 major river basins in North Carolina to simulate flows for determining if adequate water is available in the future to meet all needs, including essential water uses and ecological flows. Basinwide models are considered a practical approach to water planning because site- and project-specific evaluations require considerable time and money. However, the proposed planning method used by DENR will not replace site-specific studies needed for a specific environmental assessment or permit review. This proposed method will not vary existing permits/licenses or impose additional regulatory requirements on current permittees related to water quality and water quantity. Per the statute, DENR is required to provide status reports to the N.C. Environmental Review Commission (ERC) on the development of basinwide hydrologic models no later than November 1 of each year, beginning in 2011.

The Session Law defines ecological flow as "the stream flow necessary to protect ecological integrity." Ecological integrity is defined as "the ability of an aquatic system to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to prevailing ecological conditions and, when subject to disruption, to recover and continue to provide the natural goods and services that normally accrue from the system." The statute directs DENR to "characterize the ecology in the different river basins and identify the flow necessary to maintain ecological integrity."

Session Law 2010-143 directs DENR to "create a Science Advisory Board to assist the Department in characterizing the natural ecology and identifying the flow requirements." The statute directs DENR to ask the EFSAB "to review any report or study submitted to the Department for consideration that is relevant to characterizing the ecology of the different river basins and identifying flow requirements for maintenance of ecological integrity." Per Session Law 2010-143, the EFSAB shall include representatives from: the N.C. Division of Water Resources (DWR); the N.C. Division of Water Quality (DWQ); the N.C. Wildlife Resources Commission (WRC); the N.C. Division of Marine Fisheries (DMF); and the N.C. Natural Heritage Program (NHP). The statute also directs DENR to invite participation by: the U.S. Fish and Wildlife Service (USFWS); National Marine Fisheries Service (NMFS); and individuals with expertise in aquatic ecology and habitat from organizations representing: agriculture; forestry;

manufacturing; electric public utilities; and local governments; and other individuals or organizations with expertise in aquatic ecology and habitat.

While the role of the EFSAB appeared rather clear from the statutory language, it was subject to early discussion and interpretation by the members. After preliminary discussions and review of the statute, the EFSAB agreed any recommendations regarding ecological flows would be made for the purpose of water resource planning, not water-use permitting. The EFSAB also agreed to recommend scientifically-based methods or approaches, and ecological flow requirements, which may or may not be numerical. Although the EFSAB is charged with developing a statewide approach, this approach does not substitute for site-specific evaluation when that is needed and it does not prevent the DENR from requesting a site-specific evaluation. The EFSAB agreed to provide two primary deliverables: 1) characterization of aspects of the ecology in different river basins relevant to ecological flows; and 2) identification of the flow regimes necessary to maintain ecological integrity. The EFSAB is neither responsible for recommending how DENR responds to a water-availability issue nor responsible for advising DENR on how to use the EFSAB recommendations and research products.

1.3 DENR's Actions Establishing the EFSAB

DENR through its DWR extended invitations to 16 members of the North Carolina scientific and technical community with expertise in aquatic ecology and habitat to serve on the EFSAB. The EFSAB has a total of 16 primary members, as well as alternates, from the following agencies or organizations: DWR, DWQ, WRC, NHP, DMF, Environmental Management Commission (EMC), USFWS, NMFS, USGS, American Water Works Association (AWWA), the N.C. Department of Agricultural and Consumer Services (NCDA&CS), the N.C. Forest Service (NCFS), utilities, local governments, academic institutions, and environmental non-governmental organizations.

In addition, the DWR contracted with the N.C. State University's Natural Resources Leadership Institute and program for Watershed Education for Communities and Local Officials to assist in the development of the EFSAB charter, lead development and organization of the agenda for each EFSAB meeting, facilitate the EFSAB meetings, produce written minutes for each meeting, and assist with other process management tasks. DWR produced and hosts an ecological flow website with pages defining ecological flow and discussing the importance of ecological flows to North Carolina. The website documents the activities of the EFSAB, including presentations, literature reviewed, meeting recordings and minutes.

1.4 Activities of the EFSAB

The EFSAB met 28 times with the first meeting convened November 8, 2010 and the last meeting held October 23, 2013. During the initial meetings, the EFSAB established a charter that included the purpose, goals, procedural rules, and responsibilities for the EFSAB members, DWR and the facilitation team. Decision-making by the EFSAB was based on consensus principles. The EFSAB used small-group break-out sessions, brainstorming, open discussions, and trial balloon techniques to discuss and clarify topics, capture individual member's concerns, and put forth potential methods to achieve the EFSAB's ultimate goal of advising DENR on its charge of characterizing the ecology of the river basins and identifying the flow regime necessary to maintain ecological integrity. To address the latter charge, the EFSAB spent the majority of its time reviewing ecological flow literature, hearing and discussing presentations from ecological flow experts, and reviewing research conducted in North Carolina.

2 STATE OF ECOLOGICAL FLOW SCIENCE

2.1 Characterization of the Ecology of North Carolina Rivers

Physical, biological, and chemical processes determine the presence, absence, abundance and diversity of species, as well as habitat types present within streams. These processes, coupled with hydrology, determine the ecology of streams. In general, the freshwater ecology of the streams of North Carolina is characterized by intermittent and perennial flowing systems with diverse aquatic fauna (depending in part on detrital energy derived from terrestrial plants at the headwaters) and productive larger streams with resident diadromous fishes near the estuaries. North Carolina streams show distinct seasonal patterns and variation in their flow.

The ecology of freshwater streams is as diverse as the landscapes across the state. Streams in North Carolina vary from small tumbling mountain waterfalls and meandering blackwater streams to large piedmont and coastal rivers. North Carolina streams include coldwater communities, mostly in the higher elevations of the mountains where summer water temperatures generally do not exceed 22 degrees Celsius (72°F). Coolwater streams occur in lower elevations in the mountains and piedmont with maximum temperatures between 22-25 degrees Celsius (72-77F).

Warmwater streams are flowing waters with maximum water temperatures typically greater than 25°C (77°F). Outstanding Resource Waters (ORW) are designated in nearly all of the basins in North Carolina and all of the physiographic regions. On the other end of the spectrum, there are impaired streams in all of the basins and each of the physiographic regions. Specific information relative to the streams and watersheds in the state can be obtained from DENR's basinwide plans.

2.1.1 Mountain Streams

The freshwater streams of the mountains are located within the Blue Ridge Physiographic Province of the Appalachian mountains of western North Carolina. These watersheds are characterized by forestland cover, extreme relief and high precipitation resulting in numerous streams with permanently flowing, steep gradient channels, and well-oxygenated waters. These streams provide habitats for diverse aquatic life and complex ecological functions. Much of the land within the mountains is sparsely developed. Major stream systems draining the Blue Ridge Province in North Carolina include the Little Tennessee, Hiwassee, French Broad/Nolichucky, Watauga and New rivers (part of the Mississippi River drainage), and the Savannah, Broad, Catawba, and Yadkin rivers (part of the Atlantic Ocean drainage).

Mountain streams typically have relatively steep gradient in many reaches. Most tributaries are high gradient streams with cold water capable of supporting trout populations in the upper reaches. Some tributaries and upper mainstems have cool water capable of supporting communities characterized by smallmouth bass.

The aquatic communities typically found in mountain drainages are significantly different than those found in drainages of the piedmont and coastal plain. Mountain streams host some of the most diverse aquatic communities within North Carolina. They are home to a variety of rare species, including crayfish, mussels, fish, aquatic insects, and amphibians. For example, the

25-mile reach of Little Tennessee River between the town of Franklin and Fontana Lake has a faunal diversity rivaling any in the state.

The hydrology of most streams and rivers in the mountains is relatively unaltered. However, a number of hydropower projects significantly alter flows, and therefore stream ecology, by operating in a peaking mode or diverting water around long stretches of stream channel. The ecology of mountain streams is also influenced by numerous culverts and barriers that impede the movements of aquatic organisms.

2.1.2 Piedmont Streams

Streams in the Piedmont Physiographic province of North Carolina flow toward the Atlantic Ocean. Many piedmont streams originate in the mountains, eventually transitioning across the Fall Line before reaching the coastal plain. Piedmont streams can be considered as intermediate to the higher gradient, cooler streams of the mountains and the low gradient waters of the coastal plain. In addition, Piedmont streams typically lack the large boulders of mountain streams yet have more substrate size diversity than the sand dominated streams of the coastal plain. The majority of aquatic communities in piedmont streams are considered warmwater, although some coolwater communities are present in the foothills portions of some basins.

Increasing nutrient enrichment, stormwater from urban areas, and wastewater are the primary impacts to water quality in eight basins of the Piedmont. Most of these impacts are associated with urban areas. Land conversion from forest and agricultural practices to suburban uses is occurring throughout the piedmont, especially in the area known as the "Piedmont Crescent" which extends from Charlotte to Greensboro to Raleigh, often resulting in impacts to riparian habitats.

Nearly all of the large reservoirs in the state are found in the piedmont. Reservoirs have a significant influence (positive and negative) on the hydrologic regime of the rivers downstream of their dams and transform hundreds of miles of riverine habitat into lakes. This is particularly true in the Catawba, Roanoke and Yadkin basins.

Present in the piedmont region are streams in largely forested areas with comparatively undeveloped catchments and very good water quality. In recent years, streams of the piedmont have experienced recurring moderate to severe drought. The drought conditions have led to acute awareness of the limits of availability of freshwater for drinking, recreation, and assimilation of discharge effluent.

Changes in hydrology and habitat condition have altered the biological communities of many piedmont streams and rivers. For example, many species requiring flowing water and good water quality have been replaced by habitat generalists that can tolerate a variety of conditions. Only a small percentage of piedmont streams, such as the upper Tar and Roanoke, presently support a diversity and abundance of freshwater mussels similar to historic distributions.

2.1.3 Coastal Plain Streams

Freshwater streams of the coastal plain are located within the inner and outer divisions of the Coastal Plain Physiographic provinces. Coastal plain streams are characteristically low to medium gradient, with sandy to muddy substrate that provides habitat to warmwater adapted communities. Groundwater and surface water can be tightly linked in the coastal plain. Further, water quantity and quality are closely linked as flow has important effects on salinity and dissolved oxygen concentrations.

The freshwater and estuarine streams in the coastal plain have different origins. Many freshwater streams in the coastal plain region are non-tidal streams originating in the coastal plain. A very small number of non-tidal stream reaches present along the westernmost boundary of the Inner Coastal Plain Physiographic province originate in one of the five piedmont basins and are typically medium gradient streams in the upper reaches. Saline, tidal streams originating in the coastal plain are present along the eastern boundary of the Outer Coastal Plain. Bi-directional flow from wind-driven and astronomical tides may reach into the inner coastal plain rivers and streams.

Natural communities in coastal plain streams include in-channel and floodplain communities that support resident and non-resident migratory fishes, and many species adapted to blackwater and swamp conditions. Riparian floodplains and instream aquatic vegetation associated with coastal plain stream systems influence the aquatic ecology of the coastal plain region. Seasonal hydrologic variations, such as flooding, are important to these flood plain forest communities as well.

The species and ecology in coastal plain streams are often different from those found in inland waters. For example, diadromous fish (fish that migrate between fresh and salt water) require high seasonal flows to cue spawning. Flow in these streams is important during both spawning periods and other times to allow juvenile fish growth within freshwater reaches. Ditching and channelization are extensive, and links between natural and engineered waterways are common with resultant modified flows. Barriers, such as culverts and low head dams, restrict fish movements, particularly diadromous fish and are an issue in many coastal plain and inland watersheds.

Many ecologically and economically valuable estuarine species are dependent on freshwater flows in the coastal plain streams to maintain low-salinity conditions. The position of the salt wedge is a condition critical for transitional communities. Examples of the aforementioned estuarine species include southern flounder, Atlantic croaker, spot, menhaden, bay anchovy, blue crab, white shrimp, and striped mullet. Flows that trigger spawning are also critical for the integrity of these systems. Flows during larval and juvenile growth and development are equally important.

2.1.4 Headwater Streams

The majority of stream miles in North Carolina are classified as headwater streams (drainage area <10 km^2) (Olivero and Anderson 2008). Headwaters include the smallest parts of streams, are located in the extreme upper portions of a watershed, and are the furthest distance from the stream's mouth. The origin of headwater streams varies per topography and geology, as well as the stream's location within the state. For example, headwater streams in high gradient areas usually contain large rocks and have high velocities, whereas headwater streams in low gradient areas are abutted by large floodplain areas and have low velocities.

Headwater streams originate in almost every type of terrestrial community from undeveloped watersheds to highly developed watersheds containing impervious surfaces and agricultural areas. Headwater streams have small drainage areas, higher elevations, and are more prone to dewatering in comparison to downstream waterways. Headwater streams provide habitat for numerous species and play a significant role in the removal of pollutants, nutrients and sediment, assist in flood control, and provide groundwater recharge.

Headwater streams are narrower and shallower than larger streams and rivers, and the water in headwater streams contacts the streambed and banks more regularly than in larger streams and rivers. The health of and impacts to headwater streams affects the health, water quality, and species composition and abundance of downstream systems. Human alterations, due to agricultural and urbanization, mainly in the more heavily populated areas of the state, have altered or eliminated headwater streams.

There are limited hydrologic data from headwater streams within North Carolina. Based on a GIS evaluation, roughly 8% of the 284 USGS stream gages in North Carolina are located on headwater streams. Discharge estimates for ungaged streams must be derived from mathematical regression equations based upon relationships of drainage area and precipitation. Using these equations, the USGS in cooperation with the State has evaluated low-flow characteristics statewide and for selected streams in several drainage basins in North Carolina including the Roanoke, Neuse and Cape Fear (Geise and Mason 1993, Weaver 1996, Weaver 1998). In addition, discharge estimates can now be generated through the use of sophisticated, proprietary models such as WaterFALL (for further information see Appendix D).

Biological data from headwater streams in North Carolina are also limited. In particular, the biological data used in the RTI/USGS analyses (Appendix D) were generated from the DWQ "Stream Fish Community Assessment" and "Benthic Macroinvertebrate Assessment" datasets. Roughly 10% of the invertebrate sampling sites and 15% of fish sampling sites are located in headwater streams. These percentages are in contrast to nearly 72% of invertebrate and 50% of fish sampling sites located in the next class, Creeks (drainage area ≥10km^2 and <100 km^2) (Olivero and Anderson 2008).

2.2 The Importance of Flow in Riverine Systems

Flow is generally considered the "master variable" of riverine systems, including adjoining riparian areas, because it is always a determinant of water quality, biology, physical habitat, and energy transfer (Poff et al. 1997, Annear et al. 2004). All components of the flow regime (magnitude, duration, frequency, timing, and rate of change), including natural variability, are important to maintaining ecological integrity. Natural variability of flows includes intra-annual and inter-annual variability and consists of extreme low flows, low flows, high flow pulses, small floods, and large floods. Collectively, these concepts are known as the "natural flow paradigm" (Poff et al. 1997).

Maintaining flow variability benefits native species that have adapted to such variability and inhibits invasive species from flourishing (Poff et al. 1997, Cummins et al. 2011). High flows restructure the channel profile through transport of substrate, bank scour and suspension of organic matter from the riparian zone; benefit reptiles and amphibians by refilling vernal pools; and also function as cues for spawning and migration. Low flows benefit top predators by concentrating prey and plant communities by providing habitat for the establishment of submerged aquatic vegetation and floodplain plant species. Seasonal low flows may also benefit freshwater mussel species by improving spawning and the release of glochidia in the presence of host fish species (DePhilip and Moberg 2010).

Many studies have shown that altering one or more flow regime components can significantly impact biota, including fish, mussels and aquatic insects (Freeman et al. 2001, Freeman and

Marcinek 2006, Knight et al. 2008, DeGasperi et al. 2009, Kennen et al. 2009, Rypel et al. 2009, Carlisle et al. 2010, Kanno and Vokoun 2010, Peterson et al. 2011, Mims and Olden 2012, McManamay et al. 2013). A recent meta-analysis showed that, of the 165 studies reviewed, 92% indicated a reduced ecological condition when flows were altered (Poff and Zimmerman 2010). However, it was noted that the data are often noisy and statistical relationships are not always strong. Many streams and rivers in North Carolina have already been subject to flow alteration.

2.3 Strategies to Determine Ecological Flows

There are two general strategies that have been used to determine ecological flows: habitat response models and biological response models. A habitat response model is one in which the quantity and quality of available habitat is measured relative to variation in flows. A biological response model is one in which the composition and structure of the biological community is measured relative to variation in flows. Traditional efforts to understand the impacts of altering hydrology often focused on the relationship of flow to habitat availability (Stalnaker et al. 1995, Washington Department of Ecology 2010). Although such habitat response models are an indirect and intermediate measure of expected biological response, they are useful when time and money limit the implementation of biological studies. Often, habitat models utilize habitat use or preference curves for guilds of species to ensure that all types of habitat are represented in the analysis (Vadas and Orth 2000, Persinger et al. 2010).

North Carolina has relied heavily on habitat response models, such as PHABSIM (Physical Habitat Simulation), when conducting site-specific flow studies. PHABSIM is a specific model designed to calculate an index to the amount of microhabitat available for different life stages of aquatic organisms at different flow levels, incorporating two major analytical components: stream hydraulics and life stage-specific habitat requirements. DWR, at the request of the EFSAB, conducted additional analysis of PHABSIM sites in the piedmont and mountain portions of North Carolina in an effort to better demonstrate how flow and habitat availability (response) impact biological communities.

Additionally, a new framework to determine ecological flow regimes for large geographic areas was examined. The Ecological Limits of Hydrologic Alteration (ELOHA) approach outlines a step-wise process that involves establishing a hydrologic foundation, classifying rivers, and determining flow-ecology relationships before entering a social process to develop flow regime standards (Poff et al. 2009). The classification step has been used elsewhere by several researchers, including those using only hydrologic parameters (Henriksen et al. 2006, McManamay et al. 2011a) and those using other basin characteristics (Olivero and Anderson 2008, Liermann et al. 2011, McManamay et al. 2011b, Olden et al. 2011). Other basin characteristics often include metrics such as water temperature, gradient (also referred to as slope), stream size, and geology.

Many other states and regions have undertaken efforts to determine ecological flow standards. The EFSAB reviewed many reports and policies, including:

- Alberta (Locke and Paul 2011; also Clipperton et al. 2003)
- Canada (Department of Fisheries and Oceans 2013; Linnansaari et al. 2013)
- Connecticut (Connecticut Department of Environmental Protection 2009)
- Georgia (Evans and England 1995)
- Michigan (Hamilton and Seelbach 2011)
- Potomac River Basin (Cummins et al. 2011)

- Nine case studies (Kendy et al. 2012)
- Pennsylvania (Apse et al. 2008)
- South Carolina (de Kozlowski 1988; Bulak and Jobsis 1989)
- Susquehanna River Basin (DePhilip and Moberg 2010)
- Texas (Texas Commission on Enviromental Quality et al. 2008)

This literature review revealed that a variety of approaches have been used to determine ecological flows and the flow standards can be categorized into three basic types – minimum flow thresholds, statistically-based standards, and percentage of flow standards. Minimum flow thresholds include 7Q10, September median, and monthly median. Other minimum flow thresholds are based on the Tennant method, which is a percentage of mean annual flow, varying by month (Tennant 1976). Statistically-based standards consist of a series of metrics designed to mimic various flow components (e.g., low flows, high flows, flood pulses) within a range determined from a statistical analysis of the past hydrograph. This type of flow recommendation typically consists of a set of target flow magnitudes, durations and frequencies for each month or season. The percentage of flow standard allows only a certain percent of flow to be extracted for off-stream use; the remainder is left in the stream. Minimum flow thresholds do not retain intra- and inter-annual variability like percentage of flow approaches.

Literature on flow requirements for coastal systems was also reviewed because low gradient and tidally-influenced streams function differently from other inland streams. In coastal systems, flow may play a secondary role to other factors including tides, salt concentration, and community structure and function (Jassby et al. 1995, Adams et al. 2002, Alber 2002, Mattson 2002, Powell et al. 2002). General approaches to estuarine inflow management fall into three categories – inflow-based, condition-based, and resource-based. The inflow-based approach keeps flow within selected prescribed bounds under the assumption that taking too much away is bad for the resources. A condition-based approach is one in which inflow standards are set in order to maintain a specified condition (e.g., salinity) at a given point in the estuary. Finally, a resource-based approach sets inflow standards based on the requirements of specific resources (e.g., shrimp). A separate section is presented on the assessment of ecological flows within the coastal plain (Appendix C).

2.4 Advancing the Science of Ecological Flows

In addition to reviewing the literature and input from experts who gave presentations to the group, the EFSAB analyzed the results of new research and analyses specific to North Carolina. Certain analyses were undertaken by DWR, and others were commissioned by EFSAB members to support the board's efforts. Additional research was conducted to meet the objectives of individual organizations which also proved beneficial and informative to the EFSAB. During the course of the EFSAB's tenure, it became clear that the multiple research efforts should be coordinated to maximize.outcomes and avoid duplication. Thus, an Ad-Hoc Water Research Coordination Group was formed by those entities conducting and/or funding the research. This group was not a formal part of the EFSAB, although it was instrumental in advancing the science of ecological flows and keeping the EFSAB informed. The Coastal Ecological Flows Working Group (CEFWG) was formed to assess ecological flows in the coastal plain.

2.4.1 Flow-habitat Relationships

Over the past several decades, DWR has conducted or assisted in numerous site-specific studies to evaluate the effect of water resource projects on stream flows and aquatic habitat. The types of projects have included federal hydropower relicensing, water supply reservoirs, new or expanded water supply withdrawals, and water resource planning studies.

DWR updated nine PHABSIM study sites from the piedmont and 10 sites from the mountains to analyze the influence of different flow scenarios on habitat for a variety of species, species life stages and guilds (Table 1 and Figure 1). While this analysis included streams from across the state, they were typically clustered in just a few areas. The 19 sites shown are about half of the studies in which DWR has participated. The studies are clustered because of their association with multi-site hydropower projects (mountains), water supply projects (piedmont), or the age of the study that allowed a quick update of the computational platform.

Table 1. DWR PHABSIM sites used for ecological flow analysis.

Piedmont Stream	Drainage Area (mi^2)	Mountain Stream	Drainage Area (mi^2)
Buckhorn Creek	76	Davidson River	14
Buffalo Creek	127	'East Fork' Tuckasegee River	82
Eno River	99.4	Jonathan Creek	14
First Broad River - upper	145	Nantahala River - upper	101
First Broad River - middle	202	Nantahala River - lower	143
First Broad River - lower	230	North Fork Mills River	10
Rocky River	55	Tuckasegee River	287
Tar River	437	West Fork Tuckasegee River - upper	53
West Fork Eno River	11	West Fork Tuckasegee River - lower	56
		Whiteoak Creek	14

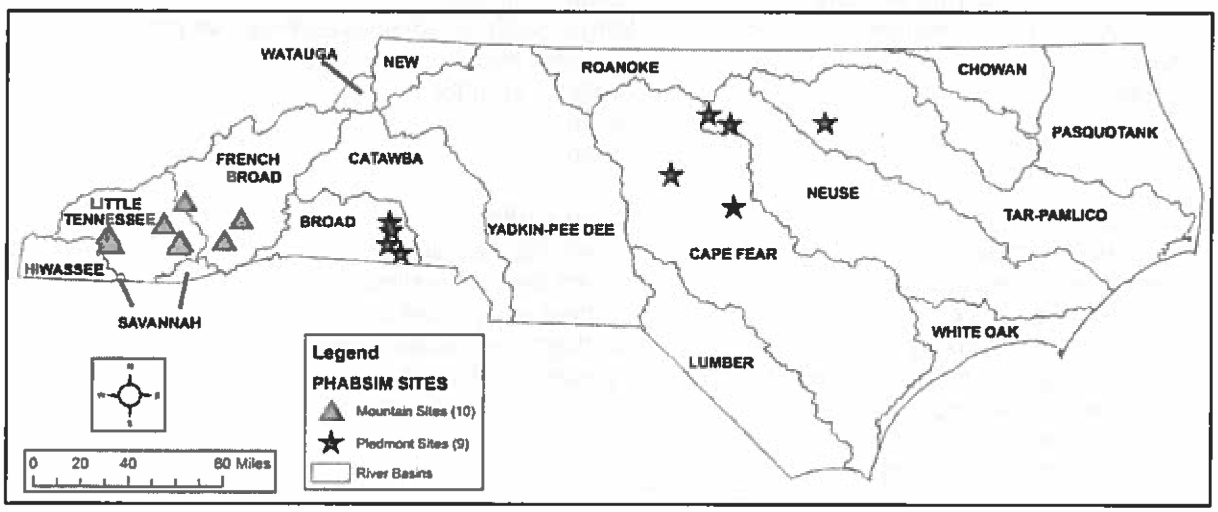

Figure 1. Location of 19 DWR PHABSIM sites analyzed for EFSAB report.

PHABSIM involves evaluating the suitability of habitat in the stream reach at a variety of stream flow levels. Individual cross-sections, or transects, are selected to represent the range of habitat types available at each site. Data are collected during at least three different stream flow conditions, and PHABSIM files are calibrated using these data to allow simulation of the physical conditions over a wide range of flows. Each study involves the collection of site-specific data for the stream channel, including cross-section profiles, depths, velocities, substrate, and cover objects. Stream velocity, depth, substrate and cover at each stream flow level are assessed relative to the habitat needs and preferences of the species or guild.

PHABSIM modeling combined with time-series analysis is a two-step approach to evaluating the availability of habitat to support a species or guild. Habitat versus flow relationships are determined by PHABSIM, and the frequencies of occurrence for different levels of habitat can then be compared for different flow regimes using time-series analysis.

The aquatic species or representative guilds selected for modeling depends upon the proposed project location, identified problem, or management goals. Table 2 list the guilds and species modeled in the piedmont and mountains for the EFSAB. Each guild or species modeled has a set of habitat suitability indices that represents how the organism responds to different stream velocities, depths, substrates, and cover objects. The suitability indices may also be referred to as preference curves (Figure 2).

Table 2. The guilds and species used for the piedmont and mountain PHABSIM analyses.

Piedmont Sites	Mountain Sites
Shallow Guild	**Shallow Guild**
shallow slow, young of year	blacknose dace spawning
shallow slow, aquatic vegetation cover	blacknose dace fry
shallow slow, woody debris cover	blacknose dace juvenile
shallow slow, coarse substrate	brown trout fry
shallow slow, fine substrate, no cover	brown trout juvenile
shallow fast lower velocity	creek chub young-of-year
shallow fast moderate velocity	creek chub adult
shallow fast higher velocity	longnose dace adult/juvenile/spawning
mayfly	northern hog sucker juvenile
stonefly	rainbow trout fry
caddisfly	mayfly
	stonefly
Deep Guild	**Deep Guild**
deep slow, cover	brown trout adult
deep slow, cover version 2	brown trout spawning
deep slow, no cover	mottled sculpin adult/juvenile
deep fast, fine substrate	northern hog sucker adult
deep fast, gravel/cobble substrate	rainbow trout adult
deep fast, coarse substrate	rainbow trout spawning
golden redhorse adult	caddisfly
golden redhorse juvenile	

PHABSIM simulates the physical conditions that would result from the range of stream flows for the selected cross-sections within a stream reach. The habitat suitability indices are correlated to the physical conditions simulated by PHABSIM in order to produce a set of values indicating the amount of habitat available for the species or guild assessed at each stream flow level for the study site. The set of values are weighted relative to the suitability of the habitat and are expressed in terms of the area per 1,000 feet of stream length. The values are referred to as the weighted usable area (WUA) (Figure 3).

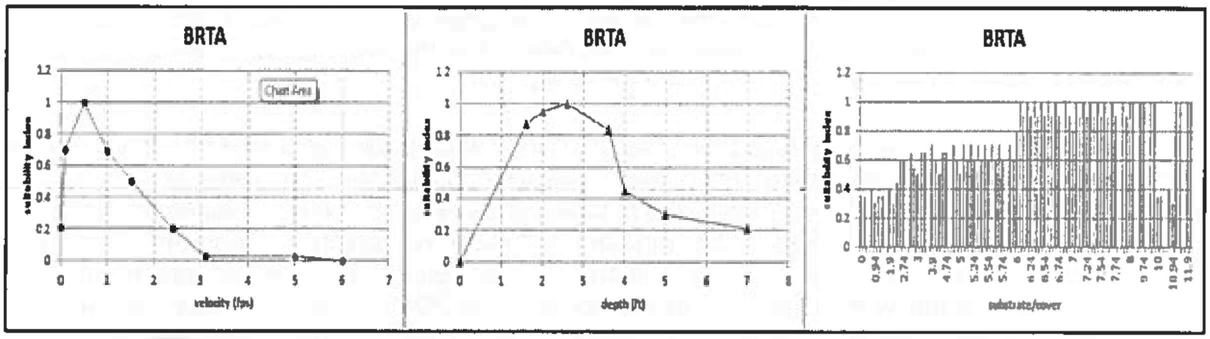

Figure 2. Example of habitat suitability curves (brown trout adult: velocity, depth, substrate-cover) used in PHABSIM modeling.

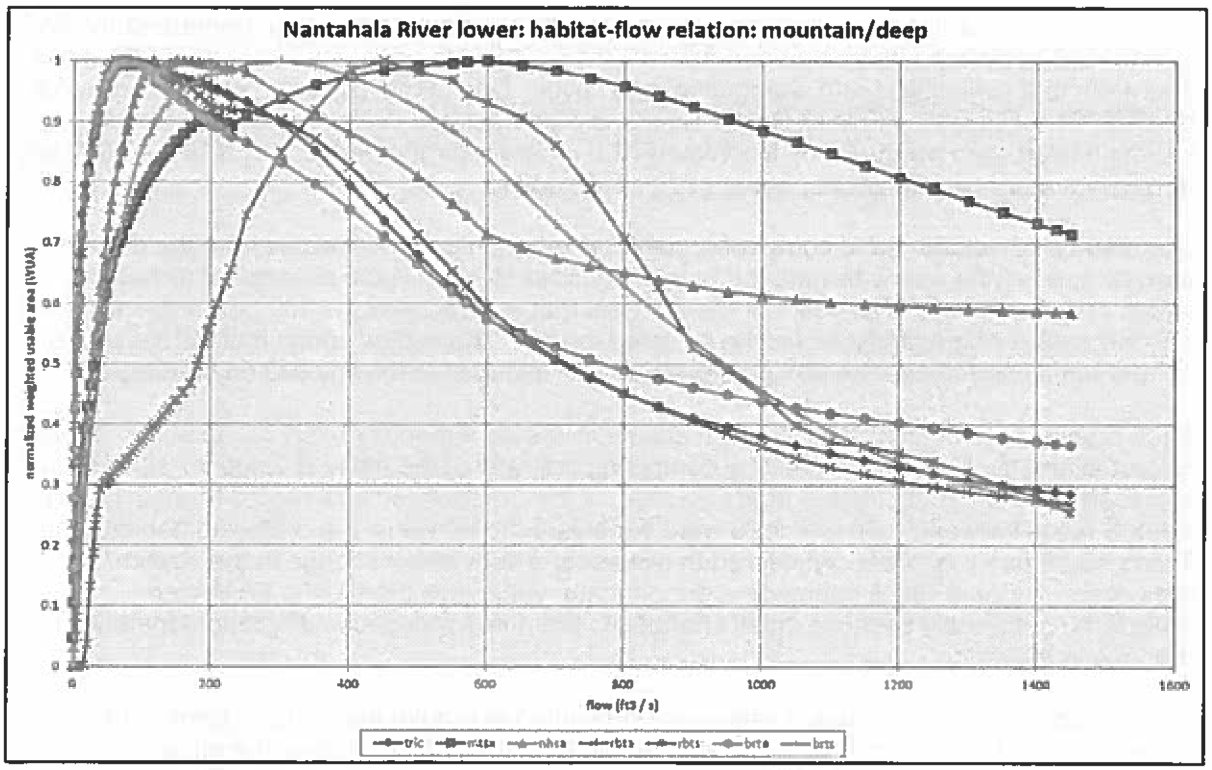

Figure 3. Example of WUA habitat-discharge relation (mountain-deep species/life stages) output from PHABSIM modeling.

The end result of PHABSIM is a habitat versus flow relationship for each guild or species that covers the range of flows evaluated. The next step – time-series analysis – uses the habitat versus flow relationship to convert a record of daily stream flows to a record of daily habitat availability. A record of daily habitat for each species or guild can be generated using records from a nearby USGS gage station or results of hydrologic modeling where daily flow records are not available. Time-series analysis can thus be combined with different hydrologic model simulations (e.g., existing withdrawals or future water use projections). The end result of time-series analysis is a comparison of habitat availability under different flow scenarios, often represented as a table or curve showing the frequency of habitat levels occurring across a range of flows for various hydrologic scenarios. The output of the time-series analysis is reported by month and by season with the seasons being defined as follows. Fall includes October and November, and Winter extends from December through March. Spring represents April through June, and Summer is July through September.

For the ESFAB, the studies assessed the effects of 15 flow records, separated into three groups of scenarios, which were generated using SAS software and routines. The three groups of stream flow approaches that were evaluated in time-series analysis were: (1) minimum flows (annual 7Q10, monthly 7Q10, September median, and monthly median); (2) percent of mean annual flow (MAF) (10 to 60 percent MAF in increments of 10 percent); and (3) percent of inflow (70 to 90 percent of inflow in increments of 5 percent). The 7Q10 value is typically used for determining the assimilative capacity of a receiving stream when permitting wastewater discharges. The September median flow is the lowest monthly median flow in most years and has been used by some states as a minimum flow requirement for projects.

The unregulated, or baseline, flow records used for the piedmont sites were generated by DWR from OASIS basin models for a period from 1928 to 2008 with no reservoirs or flow alterations other than that associated with changes in land cover. Due to the lack of an OASIS model for the Little Tennessee and French Broad basins, the unregulated flow records used for the mountain sites were produced by the WaterFALL program for the period from 1967 to 2006 with no reservoirs or flow alterations, and a 1970's land cover.

One method of reporting and comparing the WUA for each guild or species from the time-series analysis is a habitat metric termed Index B. The Index B value is the average of all habitat values in a month across all years of the analysis that are between the 10^{th} percentile and the 90^{th} percentile of habitat values for the selected month. The outlier values that fall below the 10^{th} percentile and above the 90^{th} percentile are not included in the calculation of Index B.

Index B values were calculated for each guild/species on a monthly basis for each flow scenario. Project alternatives were assessed by computing the ratio of the Index B value for a particular flow scenario (numerator) to the Index B value for the unregulated flow record (denominator). Index B ratios between 0.80 and 1.20 were considered to be within the preferred habitat range. Ratios <0.80 or >1.20 were considered to represent a substantial change to the stream ecosystem. Index B ratios based on a denominator value less than 1,000 WUA were considered separately because small changes in the numerator cause disproportionately large changes in the ratio.

Analysis and reporting of Index B ratios was presented in tabular and graphic form. The graphs are summarized by seasons, as defined in the time-series analysis output, for either all 19 guilds/species combined or for the deep water guilds/species and the shallow water guilds/species.

All three flow scenario groups (i.e., minimum flow, percent of MAF, and percent of inflow) for the piedmont and mountain sites generally exhibited a trend of more guilds/species failing to meet the 0.80 ratio criterion as the flow regimes departed from the unregulated baseline condition (Figures 4 and 5). In terms of the percentage of guilds exceeding the 1.20 ratio criterion, the three flow scenario groups showed differing responses in the piedmont. Most of the nine piedmont sites exceeded the 1.20 ratio criterion for all of the minimum flow and percent of MAF flow scenarios. This was also true for the percent of inflow group, except for the 85% and 90% inflow scenarios. Most of the mountain sites also generally exhibited a trend of more guilds/species exceeding the 1.20 ratio criterion as the flow regimes departed from the unregulated baseline condition (Figure 6). All of the 10 mountain sites exceeded the 1.20 ratio criterion for all of the percent MAF scenarios. The majority of the mountain sites exceeded the 1.20 ratio criterion for all of the minimum flow and percent of inflow scenarios, except for the monthly median, 85% inflow and 90% inflow scenarios.

In general, 12 of the 19 PHABSIM sites in the piedmont and mountains showed a habitat response in the preferred range for all seasons under one or more of the following three flow scenarios: monthly median, 85% inflow and 90% inflow. Four of nine sites in the piedmont and eight of 10 sites in the mountains had all seasons within the preferred habitat range for one or more of the three flow scenarios. In the piedmont, the lower First Broad River site was within the preferred range for the monthly median flow scenario and the 90% inflow scenario. Buffalo and Buckhorn creeks and Tar River were within the preferred range for the 90% inflow scenario. Tar River was also within the preferred range for the 85% inflow scenario. In the mountains, the monthly median flow maintained the Tuckasegee and lower Nantahala rivers within the preferred range for all seasons. Davidson and upper Nantahala rivers and Jonathan Creek were within the preferred habitat range for the 85% inflow scenario, while the 90% inflow scenario maintained seven of the ten sites within the preferred range.

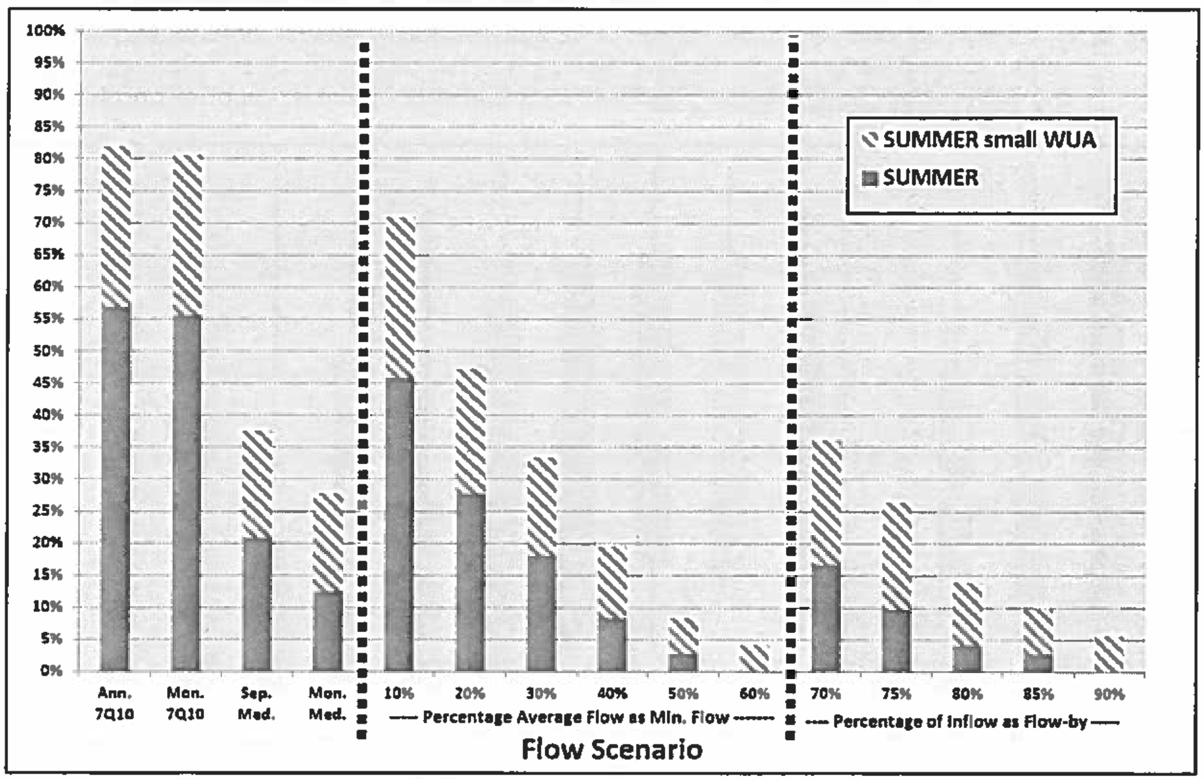

Figure 4: Total percent of eight piedmont deep guilds/species not meeting the 0.80 habitat criterion under 15 flow scenarios at nine piedmont sites in Summer. Visit the DWR ecological flow web site for a complete set of habitat response graphs.

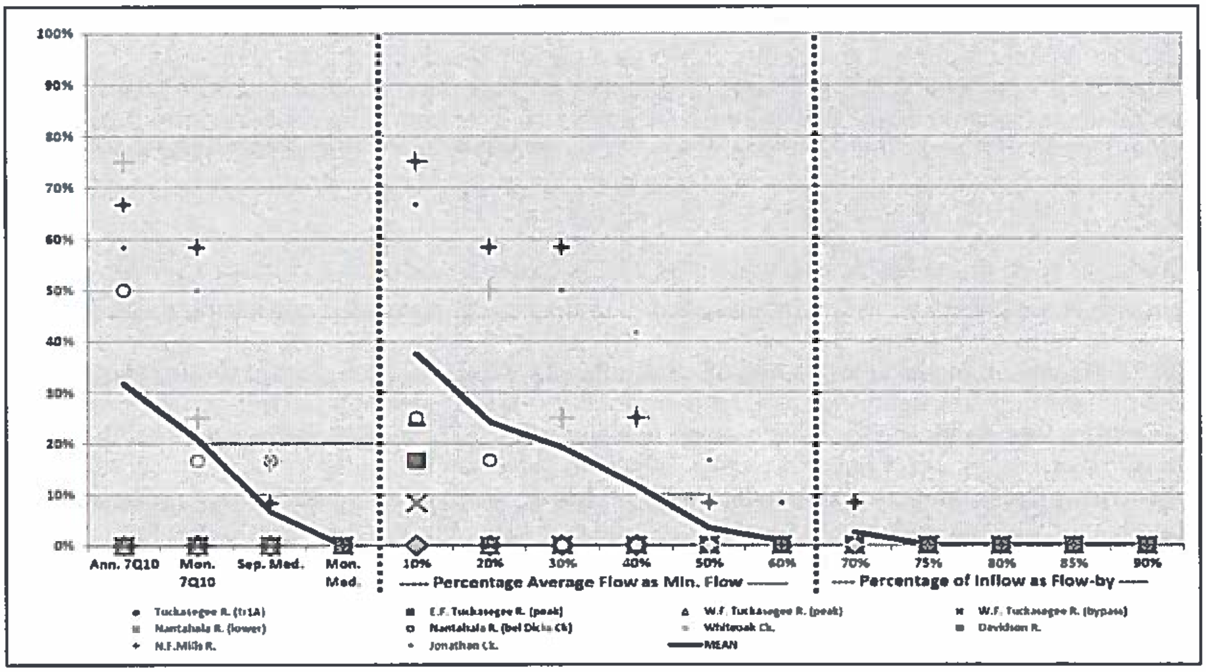

Figure 5. Total percent and associated mean of 12 shallow guilds/species not meeting the 0.80 habitat criterion under 15 flow scenarios at ten mountain sites in Spring. Visit the DWR ecological flow web site for a complete set of habitat response graphs.

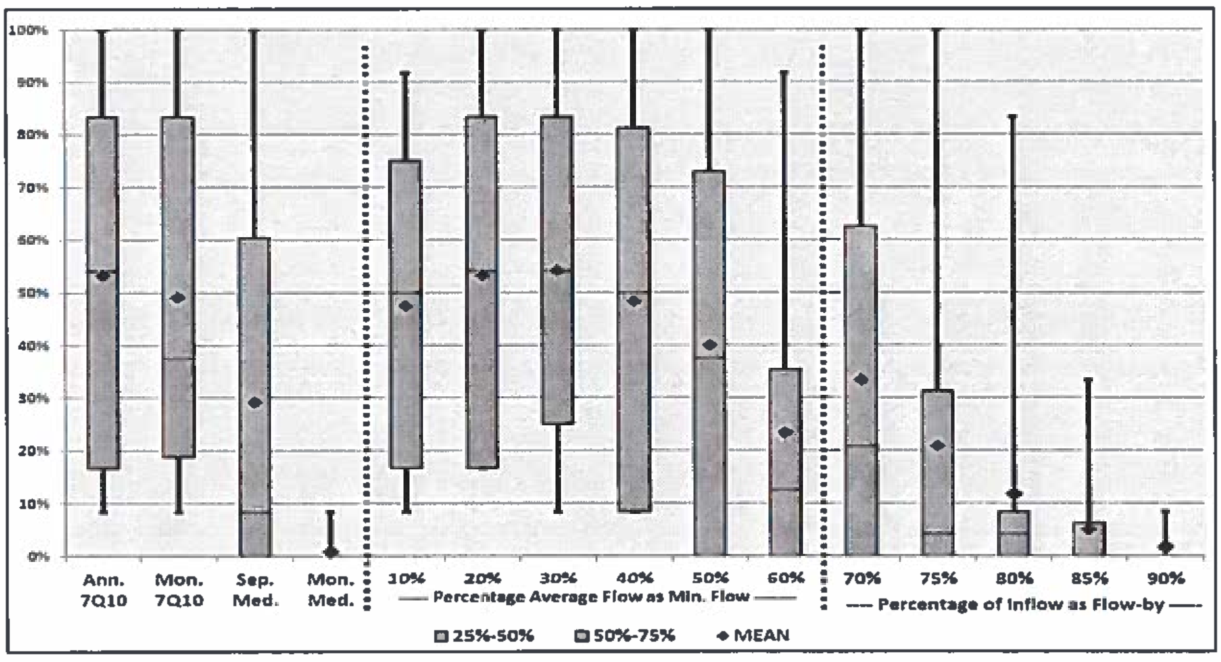

Figure 6: Mean, range, and quartiles of the percentage of 12 shallow guilds/species exceeding the 1.20 habitat criterion under 15 flow scenarios at ten mountain sites in Spring. Whiskers represent the range of values and the boundary between the red and blue boxes represents the median value. Visit the DWR ecological flow web site for a complete set of habitat response graphs.

2.4.2 Flow-ecology Relationships

Ecological flow regime recommendations specific to North Carolina can be developed by determining how biota in streams respond to changes in flow. One approach involves relating biological conditions to flow across a range of flow conditions (space for time approach) or by changes in biological conditions at a site over time. Another approach is to track biotic conditions over time to changes in flow. Organizations outside of the EFSAB tried both approaches and reported their results to the Board. The primary biotic conditions considered for both approaches are related to community structure of fish or macroinvertebrates. The most information is on community structure of fish and benthic invertebrates. Ecosystem condition and ecological integrity are inferred from fish and benthic communities in most cases.

Ecological integrity involves the interplay of both ecosystem structure and function and the ability to respond to environmental perturbations. Functional indicators of ecosystems are particularly difficult to measure directly, and structural indicators have had a long history of defining function in environmental management (Brinson and Rheinhardt 1996). Without statewide data on ecosystem structure and function, the EFSAB relied on fish and invertebrate community composition to infer ecological integrity.

Fish and benthic macroinvertebrates were evaluated as indicators of ecological integrity. Two components of the ecology of these assemblages were assessed: (1) habitat availability and (2) species distribution. Habitat availability of both assemblages was used in the PHABSIM approach (above). Species distribution approach was assessed by RTI International (RTI) and USGS. Sensitive indicators for the latter approach were designated as the Shannon-Weaver Diversity Index of the riffle-run fish guild and the taxa richness of the EPT benthos (the number of mayfly, stonefly, and caddisfly taxa). These indicators are correlated with ecodeficits, a measure of flow deficiency over the period of evaluation (typically the period of record), so the species' responses reflect recovery (or lack of it) from environmental perturbations.

RTI and USGS conducted numerous statistical analyses to find meaningful relationships between several fish and aquatic insect metrics and various flow metrics. They used the space for time approach with 649 fish and 1,227 benthos sites deemed wadeable from nearly all major river basins in North Carolina. Although wadeable streams include some larger rivers, there was a lack of information from the largest rivers and many coastal systems.

Initially, the efforts attempted to include other explanatory factors, such as stream size and basin characteristics, but these were unsuccessful. Ultimately, significant relationships were found between six flow metrics and Shannon-Weaver Diversity Index of the riffle-run fish guild and richness of benthic (Ephemeroptera, Plecoptera, Trichoptera) species. The six flow metrics included the annual and seasonal (winter, spring, summer, and fall) ecodeficits and reductions in the average 30-day minimum flow. Figure 7A and B presents responses of riffle-run fish guild diversity (Figure 7A) and benthic EPT richness (Figure 7B) responses to summer ecodeficit. Refer to Appendix D for additional information regarding the methods and results of the project that developed the flow-ecology relationships for fish and benthos in North Carolina.

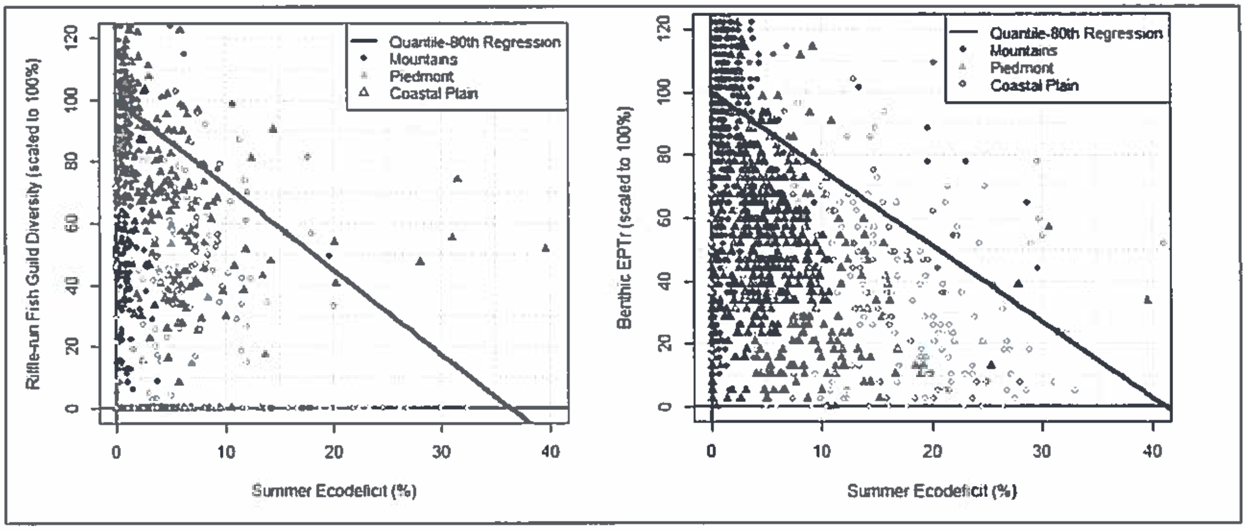

Figure 7. Flow-ecology relationships for: (A) the Shannon-Weaver diversity of the riffle-run fish guild (n=649) and (B) benthic EPT richness (n=1,227) in response to summer ecodeficits in wadeable streams in North Carolina.

The Nature Conservancy (TNC) analyzed spatial-temporal patterns of changes in flow and biota over time and explained how they are relevant to ecological flow guidelines. While the primary project purpose was to assist TNC in prioritizing conservation areas, it also was designed to provide meaningful information to the EFSAB to develop ecological flows.

Fish diversity and abundance at 141 sites in four North Carolina river basins (Roanoke, Cape Fear, Tar, and Little Tennessee) were compared to flow for the period of 1992 - 2009. These sites were in wadeable portions of streams and rivers, so data are lacking from large rivers. Many sites saw relatively little change in fish diversity and abundance over time. However, fish abundance and diversity declined in portions of the Cape Fear and Tar basins.

To understand the direct influence of water withdrawals, only sites located downstream of known water withdrawals were analyzed further. While only 14 data points fit this criterion, they showed a negative relationship between fish diversity and the relative size of the water withdrawal. While the relationship was statistically significant, the explanatory power of the relationship was small due to the small sample size. With that caveat in mind, the analysis showed a 5-10% decline in species diversity relative to a withdrawal equivalent to 10% of the mean annual flow. A withdrawal of 50% of the mean annual flow resulted in a 25- 30% decline in species diversity.

2.4.3 Attempts at Stream Classification

DWR worked closely with Environmental Flow Specialists Inc. (EFS) on efforts to characterize and classify North Carolina streams based on flow characteristics from USGS gage data. The effort resulted in a classification scheme comprised of seven stream classes that generally reflected stream size and flow stability, and was similar to a classification produced by McManamay et al. (2011a) that had eight classes. However, further analysis by RTI comparing the two classifications found that they were not similar enough to be used interchangeably.

Analysis by RTI also found that classes generated from hydrology derived from USGS gages often differed from hydrology created from the WaterFALL rain-runoff model. This was true for both the EFS and McManamay classification frameworks. Therefore, it was concluded that neither classification approach should be extrapolated beyond the USGS gages to ungaged sites. Because of the uncertainty associated with the classes generated from either framework, it was agreed that developing flow recommendations for these different stream classes is not appropriate at this time.

3 RECOMMENDATIONS OF THE EFSAB

3.1 Statewide Ecological Flow Evaluation

To evaluate flow scenarios in most North Carolina streams, EFSAB recommends the following two strategies to assess whether ecological flows are maintained:

1. *The percentage of flow strategy using 80-90% flow-by combined with a critical low flow component as the ecological flow threshold. If the basinwide hydrologic models indicate that there is insufficient water available to meet all needs, essential water uses and ecological flows at a given location, then further review by DENR is recommended.* [Flow-by is defined as "the percentage of ambient modeled flow that remains in the stream."]

2. *The biological response strategy should be used to determine the current and future modeled biological condition of locations in the basinwide hydrologic models. DENR should evaluate the change in current and future biological condition as a decision criterion. A 5-10% reduction in biological condition is suggested as a threshold for further review by DENR.*

The EFSAB recommends a statewide approach to establishing ecological flows based on the simultaneous use of these two strategies:

3.1.1 Percentage of Flow Strategy.

Natural flow regimes are important in maintaining instream, riparian, and floodplain ecosystem diversity and resilience (Poff et al. 1997). The natural flow paradigm postulates that natural ecosystems are best protected by maintaining flow regimes close to their unaltered state in terms of the five flow components (magnitude, duration, frequency, timing, and rates of change), including intra- and inter-annual variability. The most effective mechanism for resembling a natural flow regime in altered river systems is to use a percentage of flow approach (Richter et al. 2011), also known as a "flow-by" approach. It is conceptually simple and relatively easy to implement.

As an ecological flow standard, the flow-by approach works by requiring a percentage of the "instantaneous" natural flow to remain in the river (Figure 8). The flow-by approach is being used in the US, Canada, and Europe (Richter et al. 2011, Locke and Paul 2011). The percentages typically range from 80-90%. **In the North Carolina basinwide hydrologic models, the EFSAB recommends that the ecological flow should be 80-90% of the instantaneous modeled baseline flow.**

The EFSAB recommends a flow-by range of 80-90% for several reasons. Based on results of PHABSIM analyses for North Carolina, there was no apparent threshold in the data indicating a decline in predicted habitat, and flow-by percentages greater than 80% were most consistently protective of all guilds and species modeled. Furthermore, there was no consensus on a single flow-by percentage by the EFSAB. A range of 80-90% is common in the literature and other jurisdictions. Therefore, the EFSAB recommends a range of 80-90% as protective for North Carolina streams. The EFSAB is not recommending using different values for different kinds of streams, but suggesting that DENR use its discretion to select the most appropriate value for planning purposes.

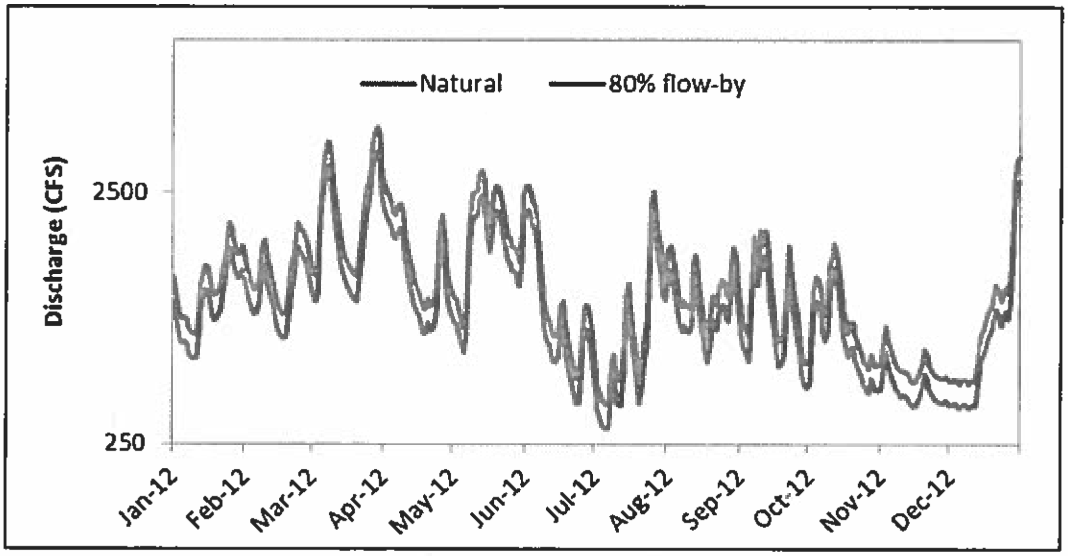

Figure 8. Example of a percentage flow-by approach.

The definition of "instantaneous" depends on how the flow-by approach is implemented. In a hydrologic planning model, instantaneous would be set at the normal time step of the model. For example, in a model that uses daily average flow, the flow-by value would be 80% of the daily flow for each day in the model's period of record. On the other hand, if a model uses a time-step of 15 minutes, the flow-by value would still be 80%, adjusted every 15 minutes. In any model, the flow-by calculation is simply the baseline flow multiplied by the flow-by percentage. In a real world implementation, the time step might be daily or every three days. Another difference in a practical application is that the flow-by might be based on the flow from the previous day, because, unlike a model, the flow for the current day is unknown. **Because the North Carolina basinwide hydrologic models use daily average flow, the flow-by value should be calculated on a daily time step.**

To the extent possible, flow regimes representing natural conditions (flow regimes without withdrawals or returns), baseline conditions (flow regimes incorporating current withdrawals and returns), and projected conditions (flow regimes incorporating current and future withdrawals and returns) should be estimated by basinwide hydrologic models. Baseline conditions will be compared with natural and future conditions to assess how much hydrology has been altered and to determine the effects of future withdrawals and returns. DENR should use this information to identify areas that have undergone substantial hydrologic change and that warrant additional attention when considering further water withdrawals. **As the hydrologic models are updated with new withdrawals and returns, baseline conditions should continue to be used as a benchmark to avoid comparisons to a continually shifting "current" condition. The recommended baseline should be the management regime extant when the legislation was passed in 2010.**

Another consideration of the flow-by approach is that it should consider cumulative effects; otherwise, multiple withdrawals could result in an overall reduction in flow below the flow-by threshold (Figure 9). Therefore, **the cumulative net upstream withdrawals at any point in the basin established after 2010 should not result in flows that are predicted to fall below the flow-by criterion.**

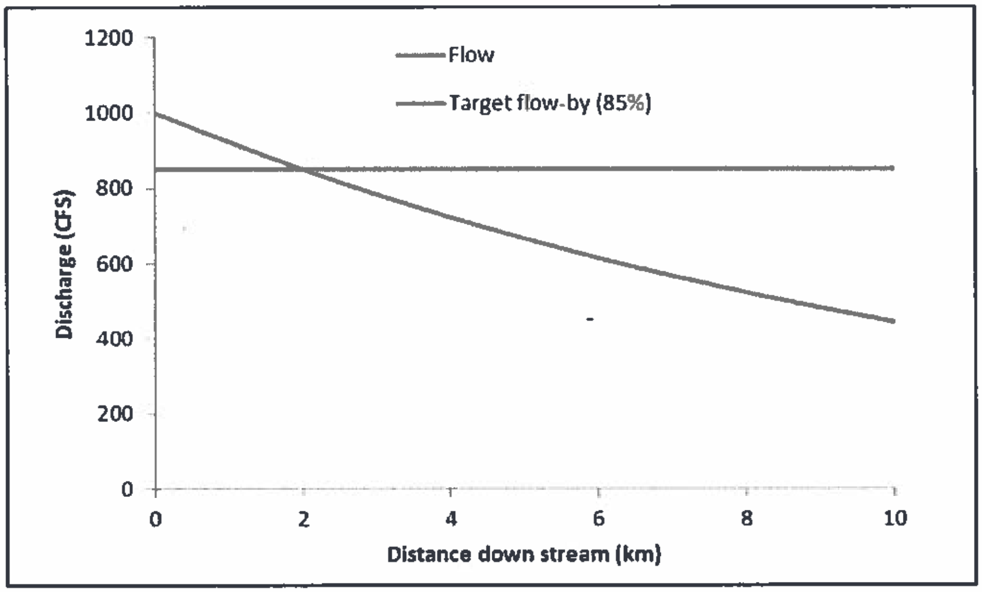

Figure 9. A percentage flow-by criterion must take into account the cumulative effects of water use along each stream. This example shows how quickly 5 withdrawals each adhering to an 85% flow-by criterion for incoming flows can result in a large cumulative loss in flow (56% reduction between 0 and 10 km) for a section of stream with no inflows (e.g., tributaries or return flows).

Percentage flow-by should be combined with a critical low-flow component that is intended to protect the aquatic ecosystem during periods of drought (Figure 10). The critical low-flow represents a point at which further human-induced reductions in flow are likely to result in unacceptable levels of risk to the health of aquatic resources. Low flow events are most critical for contributing to biological impacts. The critical low-flow criteria are derived from historic flow records and represent expected low-flows. These criteria are intended to prevent increasing the frequency or duration of extreme low flows (drought conditions) that are damaging to ecosystem health. Other jurisdictions are beginning to use a critical low flow component for protecting ecological integrity. For example, Alberta, Canada uses the monthly 20th percentile flow as a critical low flow (Locke and Paul 2011). **The EFSAB recommends DENR incorporate critical low flow as a component of the ecological flow threshold.**

Ecological flows are set as the larger of the flow-by or critical low-flow values on a daily time step. If actual flows fall below the criterion for ecological flows, DENR should evaluate current water uses to determine the best path forward/strategy to minimize ecological effects while meeting the basic needs of current water users.

As a means of assessing the potential for ecological impacts based on projections of future water use, the EFSAB recommends DENR use the baseline hydrology dataset defined above and a daily flow record containing only days when flows are between the 10th and 90th percentiles (trimmed hydrology dataset) to avoid assessments based on impacts of extreme low or high flows. The purpose of this recommendation is to assist DENR in identifying basins or nodes which are at higher risk for not maintaining ecological flows. DENR should evaluate potential for adversely impacting ecological flows at all flow nodes.

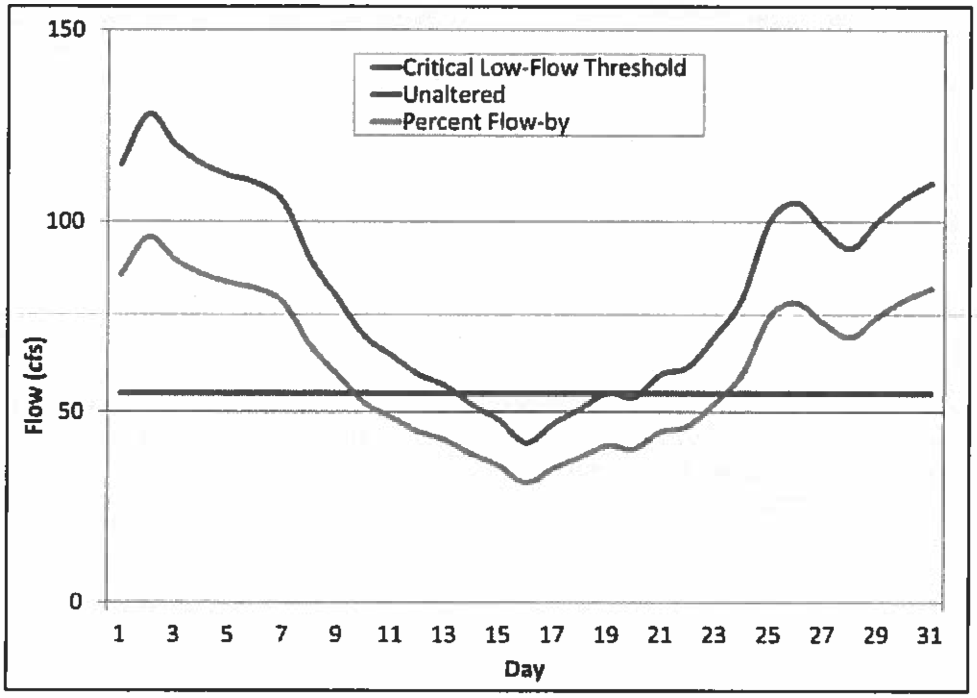

Figure 10. Percentage flow-by is shown with a critical low-flow threshold to protect against increasing the severity and duration of drought periods. The criterion for ecological flow is the larger flow value defined by the daily percentage flow-by or the critical low-flow.

Using the flow records described above, the EFSAB proposes the following approach to evaluate ecological flows at model flow nodes:

1. The ecological flow threshold should be calculated as the greater of the flow-by and critical low flow values. If none of the nodal flows from the baseline record fall below this threshold, then the risk of impact relative to ecological flows will be considered to be low and no immediate action is recommended (green flag).

2. If one or more days of the existing or projected daily model flows fall below the ecological flow threshold but all of the projected flows within the trimmed hydrology dataset remain above the ecological flow threshold, this should alert DENR to begin further review of water usage that may be contributing to the deviations (yellow flag). Management tools including water shortage and drought response plans should be evaluated for the purpose of maintaining ecological integrity.

3. Stream reaches associated with nodes having one or more days of the trimmed hydrology dataset less than the ecological flow threshold should be given additional review by DENR (red flag). Management tools including water shortage and drought response plans should be evaluated for the purpose of maintaining ecological integrity. Additional review could include actions such as conducting site-specific evaluations or review and modeling of any biological data that are available.

The establishment of ecological flows based on a combination of percentage flow-by and critical low-flow thresholds represents the best available methodology for the protection of aquatic resources. However, these methods are based on hydrologic models that may not be applicable to all streams across the state since the stream gages needed for model verification may not be available for smaller streams. These models also do not directly address the relationship between flow alteration in the state and biological effects. Fortunately, North Carolina has a well-developed biological assessment program that provides data that can be used to model the effects of flow alteration on biology.

3.1.2 Biological Response Strategy

Biological response models developed by RTI and USGS should be used to evaluate the effects of flow regimes on fish (as measured by the Shannon-Weaver Diversity Index of the riffle-run fish guild) and benthic macroinvertebrates (measured as EPT richness) on the basis of annual and seasonal (winter, spring, summer, fall) ecodeficit, and reductions in the average annual 30-day minimum flow. Ecodeficits are determined by computing the total negative change in flows between altered and unaltered flow duration curves obtained from basinwide hydrologic models (Figure 11; also see Appendix D).

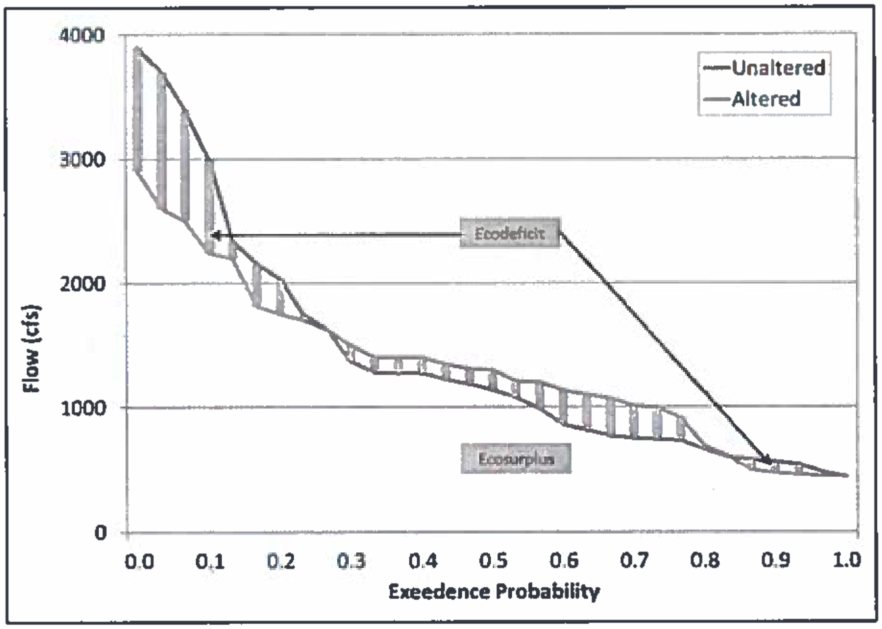

Figure 11. Ecodeficits are calculated by measuring reductions in flow between altered and unaltered flow duration curves.

These fish and benthic macroinvertebrate response models were derived from biological monitoring data collected by DENR at 649 and 1,227 wadeable streams and rivers throughout North Carolina, respectively (NCDENR 2013a and NCDENR 2013b). Quantile regressions were used to develop the relationship between the 0.8 (i.e., 80th) response quantiles of fish and benthos and ecodeficits for the annual, winter, spring, summer and fall seasons (Table 3). Figure 12A presents the 0.8 quantile regression relationship of the riffle-run fish guild Shannon-Weaver Diversity Index and summer ecodeficit and Figure 12B presents the same relationship for benthic EPT richness.

Table 3. Statewide quantile regression models (Y = A + BX) relating ecodeficit (X) to biological responses (Y) for riffle-run fish guild (Shannon-Weaver Diversity Index) and benthic macroinvertebrates (EPT richness).

Riffle-run Fish Guild: Shannon-Weaver Diversity Index						
	Intercept (A)			Slope (B)		
Ecodeficit	Value	SE[1]	p-value[2]	Value	SE	p-value
Annual	100	2.580	<0.001	-1.429	0.429	<0.001
Winter	100	2.383	<0.001	-1.353	0.530	0.011
Spring	100	2.365	<0.001	-1.653	0.332	<0.001
Summer	100	1.797	<0.001	-2.761	0.469	<0.001
Fall	100	2.326	<0.001	-2.093	0.444	<0.001
Benthic macroinvertebrates: EPT richness						
	Intercept (A)			Slope (B)		
Ecodeficit	Value	SE	p-value	Value	SE	p-value
Annual	100	2.210	<0.001	-2.344	0.387	<0.001
Winter	100	2.050	<0.001	-2.427	0.334	<0.001
Spring	100	2.009	<0.001	-2.657	0.307	<0.001
Summer	100	2.005	<0.001	-2.433	0.257	<0.001
Fall	100	1.730	<0.001	-2.341	0.166	<0.001

[1] Standard Error

[2] p-value < 0.05 is considered statistically significant

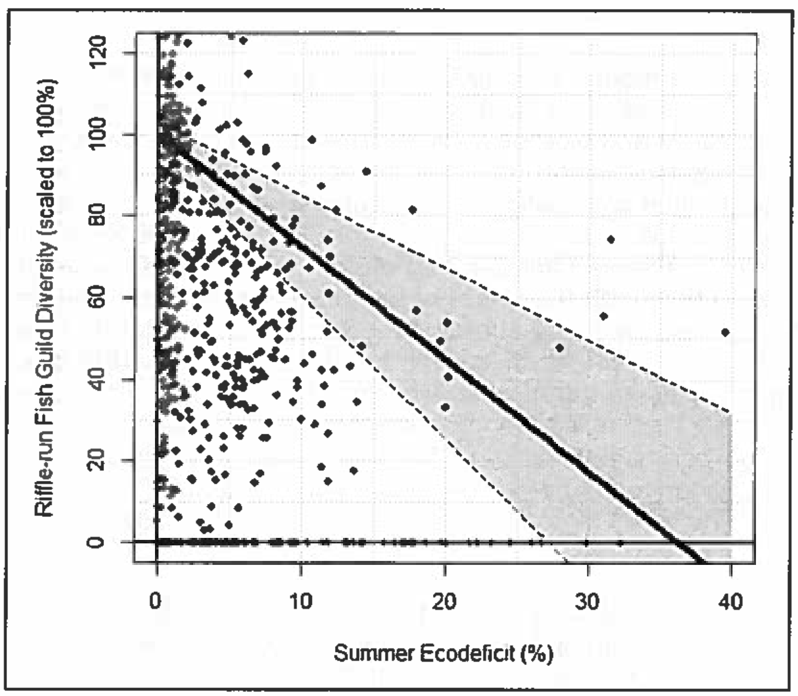

Figure 12A. Quantile regression (0.8 quantile) showing the relation between summer ecodeficit and riffle-run fish guild Shannon-Weaver Diversity Index (greyed area indicates 95% confidence interval).

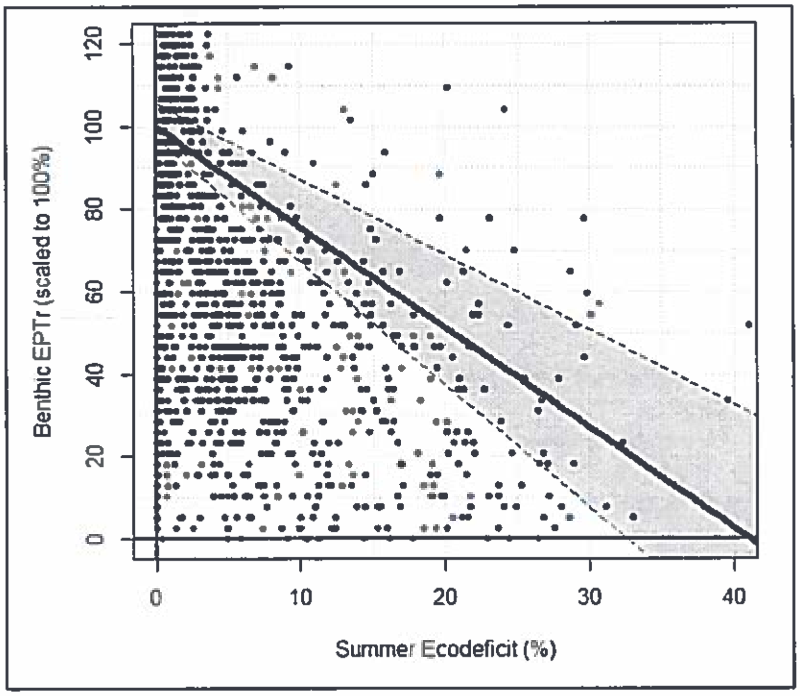

Figure 12B. Quantile regression (0.8 quantile) showing the relation between summer ecodeficit and macroinvertebrate EPT richness (greyed area indicates 95% confidence interval).

These biological response models provide DENR with an estimate of the most probable statewide effect of flow alteration on biological condition. While these models provide a direct link between flow alteration and biological effects for North Carolina streams and rivers, such models are not designed to be highly predictive for specific sites. The uncertainty is high when considering a particular time and place within a stream. Rather they provide expected and statistically significant trends under various scenarios. **Therefore, DENR should evaluate the use of these models to assess changes in biological conditions associated with projected changes in flow with the intent of developing biological criteria for implementing further review of the ecological effects of flow alteration (e.g., implementation of site specific studies such as PHABSIM). A 5-10% change in biological condition is suggested as an initial criterion for further review.** This criterion is based on the average range of EPT richness within the invertebrate condition classes (Excellent, Good, Good-Fair, Fair, and Poor) as defined by DENR (see Table 17 in Appendix D). The 5-10% criterion represents a change of one-quarter to one-half of the width of a condition class (e.g., Excellent to Good). The 5-10% criterion should be evaluated by DENR as more data are collected.

The RTI/USGS report recommended varying the criteria for acceptable change on the basis of the condition class of the stream or river. A 5% change would be tolerated for sites rated as excellent, 10% for sites rated as good or good-fair, 15% for sites rated as fair, and a minimum flow criterion for sites rated as poor. The rationale for this approach was to provide higher protection for sites with high EPT taxa richness and lower protection for sites with lower EPT taxa richness. The EFSAB decided not to adopt the RTI/USGS variable criteria because (1) it requires that the site condition be known before the criterion can be applied and (2) there was concern that the 15% acceptable change criterion was too large.

The adoption of a range (5-10%) applied statewide carries important implications. For example, EPT taxa richness at the least disturbed sites is known to vary by region (i.e., decreases from mountains to piedmont to coastal plain) and to decrease with diminishing water-quality conditions. Consequently, the amount of change (number of EPT taxa) that will be acceptable using the 5-10% criterion will vary by region (i.e., larger change allowed in the mountains and smaller change allowed in the coastal plain) and by level of disturbance (larger change allowed at sites with excellent conditions, smaller change allowed at sites with poorer conditions). While the EFSAB supports the 5-10% change criterion, it acknowledges that the application of this criterion may result in the reduction of conditions at sites with exceptional quality conditions. The EFSAB encourages DENR to consider additional protection for sites with outstanding biological characteristics.

3.2 Exceptions to Statewide Recommendation

Headwater and coastal plain streams require different criteria for the establishment of ecological flows. The following sections present recommendations for addressing these special situations.

3.2.1 Headwater Streams

There are limited biological and hydrologic data in headwater streams within North Carolina. These streams have a higher vulnerability to disturbance, and the broader statewide approach may not adequately reflect the potential for impact to ecological integrity. ***Therefore, for streams with drainage basins <10 km^2, DENR should conduct additional analyses to determine the potential for impact.***

The EFSAB recommends that DENR conduct additional review, over and above that recommended in the broader statewide approach, for proposed flow alteration of headwater streams. For the purposes of this recommendation headwater streams are defined as streams with drainage areas of <10 km^2 (3.9 mi^2). This size class threshold for headwater streams has been utilized in recent riverine assessments conducted by TNC for the Northeast (Olivero and Anderson 2008) and Southeast (Olivero-Sheldon and Anderson 2013).

3.2.2 Coastal Streams

The Coastal Ecological Flows Working Group (CEFWG) developed a framework for providing recommendations by introducing four potential approaches to determining ecological flows for coastal streams, depending on the origin of the stream, the gradient or slope of the stream and whether the stream has wind- or tidal-driven flow (Table 4):

Table 4. CEFWG proposed framework to determine ecological flows.

Origin	Gradient	Ecological Flow Approach			
		Statewide Recommendation	Habitat Relationship	Downstream Salinity	Overbank Flow
Piedmont	Medium	X	X	X	
Coastal Plain	Medium	X	X	X	
Coastal Plain	Low		X	X	X
Coastal Plain	Wind or tidally driven flow			X	X

The statewide ecological flow recommendation may be used where discharge and stage are still closely correlated. Water level stations exist within the coastal plain below modeled reaches of streams with piedmont reaches. These water levels could be correlated with the upstream or nearby flows records from USGS gage stations. When correlation meets some criteria of pattern similarity, regression can be used to extend known flows to ungaged reaches.

The low elevation, flat terrain and proximity to tidal, saline water combine to prevent the use of current hydrologic models in the coastal plain that are used to determine the flow-by and ecodeficit recommendations. Different approaches to ecological flows from those described are required, although there is a lack of detailed understanding to offer specific protocols for this region. Thus, a more general framework is recommended that categorizes coastal plain streams and identifies four ecological flow approaches to be considered based on stream category. The approaches include extension of the statewide flow-by criteria; conditions of habitat, primarily for anadromous fish; downstream salinity; and overbank flow. Each stream category may be subjected to more than one, but not all, approaches.

Flow requirements and recommendations for the viability of living aquatic resources have been developed for eastern North Carolina and for specific river basins. The DMF has developed the Coastal Habitat Protection Plan (CHPP) (Deaton et al. 2010) based on the concept of protecting habitat for protection of living marine resources, especially fish and shellfish. The fish and shellfish of concern include both residents of fresh to oligohaline waters and species that live part of their life cycle in saline waters. This approach has goals similar to the efforts of the EFSAB. The DMF should be directly engaged in establishing an approach based on CHPP and other fisheries management plans. This action should also include plans to protect threatened and endangered species.

Salinity is a key water quality factor dependent on flow. Organisms have different physiological tolerances and dependencies for salinity that may vary with life stage. The physiological ranges are directly related to reproductive, developmental and other ecological success of the organisms. Further, salinity distribution is linked to the potential for low dissolved oxygen (DO) conditions, especially in bottom waters. Affected organisms include both animals and plants. Either position of a prescribed salinity or the salinity at a prescribed position has been used by other states to index ecological flows. A recent study on the effects of future water withdrawals in Greenville, NC, used salinity within the Tar River as its indicator of effect. The study should provide insight into how salinity may be used for assessing ecological flow effects.

Overbank flow is dependent on stage with varying dependence on discharge associated with location and elevation of a reach. Riparian, freshwater wetlands are often inundated during colder months and dry or infrequently flooded during warmer months. This pattern is needed to maintain community structure and ecosystem function of these wetlands. Blackwater streams have unique characteristics derived from high dissolved organic matter concentrations and low DO originating from wetlands, combined with slow velocities. Ecological flows within the coastal plain should be sufficient to maintain the seasonal flooding regime in order to protect the ecological integrity of these wetlands, a factor not necessary for streams in the mountains or piedmont.

The framework presented here advances the assessment of ecological flows within the coastal plain but not to the extent of that in other regions. It represents a way forward, but requires further understanding of the relationships that control ecological flows and institution of assessment efforts. Such efforts can be undertaken using resources within North Carolina, but no one program within the state has the expertise or resources to fully advance and refine the framework. It will take coordination and cooperation of the agencies within DENR and the research community.

The EFSAB proposes that DENR continue to work with the CEFWG, and other agencies and organizations as appropriate to further develop this framework. Several agencies within DENR can contribute expertise and effort to CEFWG. The Albemarle Pamlico National Estuary Program (APNEP) has ecological flows as a primary mission within its Comprehensive Conservation and Management Plan (APNEP 2012). The DMF and WRC have expertise on the key species and habitats of coastal North Carolina. The expertise of the DWR is essential to extending both ecological condition of coastal ecosystems and the hydrological modeling. The Ecosystem Enhancement Program (EEP) also would have interest and relevant expertise. The Water Resources Research Institute (WRRI) and Sea Grant Program (SG) at NC State University provide a connection to the research community. All of these agencies have an interest and stake in ecological flows within the coastal plain that go beyond the immediate legislative needs directing the EFSAB.

Representatives of state agencies and others should meet to determine (1) general goals and objectives, (2) their needs within this topic, (3) expertise and resources available from each, and (4) a plan to achieve both general and individual goals. Once these agencies can establish their aggregated objectives and general approach, other organizations can be invited to participate. Other contributors should include various willing partners who participated in the EFSAB (e.g., industry and agricultural groups, federal and local government entities, environmental groups). This should include RTI International, which did not have membership on the EFSAB but contributed greatly. Initial leadership should come from someone associated with EFSAB activities, but once a path forward is determined, this requirement may not be necessary.

Coincidental to this activity should be the stimulation of research directed toward ecological flows within the coastal plain. WRRI and SG would be the likely sources of funds for this action, but other agencies may have more directed funding opportunities. (See appendix of CEFWG report for more information.)

3.3 Additional Recommendations

3.3.1 Threatened and Endangered Species

The flow requirements of listed species are often not fully understood. In order to conserve state and federally listed species, the EFSAB recommends that the flow needs of these species should be considered by the DENR in addition to the standard recommendations offered in this report. For planning purposes, portions of basins (e.g., nodes) that include listed species should be treated by DENR as needing additional analysis in consultation with the WRC, NMFS and USFWS. When a decision moves beyond planning, then applicable environmental review documents will be sought from appropriate agencies. The EFSAB also encourages DENR and other appropriate agencies to support further research on the flow requirements of listed species.

3.3.2 Ongoing Validation Using an Adaptive Management Approach

There is uncertainty in the science and the existing models, thus a risk averse strategy was used when devising recommendations. Changes in climate and land use are expected to have significant effects on patterns of temperature, precipitation, hydrology and ecology. Monitoring and predicting these changes will be critical for success in maintaining ecological integrity of North Carolina's rivers and streams. An adaptive management approach is required to continually advance the science and reduce areas of uncertainty. Therefore, DENR should:

1. Emphasize new data (hydrologic and biological) collection and evaluation in headwaters, in the coastal plain, and in large rivers, recognizing that current biological models and assumptions may not address these systems.
2. Adopt/design/develop strategies to:
   a. Validate ecological thresholds (strategies should be informed by new data or research);
   b. Track the impact of flow changes when they occur;
   c. Modify characterizations, target flows, and thresholds based on new data, changing conditions (e.g., land cover, precipitation, hydrology) and lessons learned; and
   d. Georeference nodes in each hydrologic model to facilitate analysis.

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APPENDIX A – Session Law 2010-143

GENERAL ASSEMBLY OF NORTH CAROLINA

SESSION 2009

SESSION LAW 2010-143

HOUSE BILL 1743

AN ACT to direct the department of environment and natural resources to develop basinwide hydrologic models, AS RECOMMENDED BY THE ENVIRONMENTAL REVIEW COMMISSION.

The General Assembly of North Carolina enacts:

SECTION 1. G.S. 143-350 reads as rewritten:

"§ 143-350. Definitions.
As used in this Article:

(3) "Essential water use" means the use of water necessary for firefighting, health, and safety; water needed to sustain human and animal life; and water necessary to satisfy federal, state, and local laws for the protection of public health, safety, welfare, the environment, and natural resources; and a minimum amount of water necessary to ~~maintain~~ support and sustain the economy of the state, region, or area.

SECTION 2. G.S. 143-355 is amended by adding a new subsection to read:

"(o) Basinwide Hydrologic Models. - The Department shall develop a basinwide hydrologic model for each of the 17 major river basins in the state as provided in this subsection.

(1) Definitions. - As used in this subsection:

a. "Ecological flow" means the stream flow necessary to protect ecological integrity.

b. "Ecological integrity" means the ability of an aquatic system to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to prevailing ecological conditions and, when subject to disruption, to recover and continue to provide the natural goods and services that normally accrue from the system.

c. "Groundwater resource" means any water flowing or lying under the surface of the earth or contained within an aquifer.

d. "Prevailing ecological conditions" means the ecological conditions determined by reference to the applicable period of record of the United States Geological Survey stream gauge data, including data reflecting the ecological conditions that exist after the construction and operation of existing flow modification devices, such as dams, but excluding data collected when stream flow is temporarily affected by in-stream construction activity.

e. "Surface water resource" means any lake, pond, river, stream, creek, run, spring, or other water flowing or lying on the surface of the earth.

(2) Schedule. - The Department shall develop a schedule for basinwide hydrologic model development. In developing the schedule, the Department shall give priority to developing hydrologic models for river basins or portions of river basins that are experiencing or are likely to experience water supply shortages, where the ecological integrity is threatened or likely to become threatened, or for which an existing hydrologic model has not been developed by the Department or other persons or entities.

(3) Model. - Each basinwide hydrologic model shall:

a. Include surface water resources within the river basin, groundwater resources within the river basin to the extent known by the Department, transfers into and out of the river basin that are required to be registered under G.S. 143-215.22H, other withdrawals, ecological flow, instream flow requirements, projections of future withdrawals, an estimate of return flows within the river basin, inflow data, local water supply plans, and other scientific and technical information the Department deems relevant.

b. Be designed to simulate the flows of each surface water resource within the basin that is identified as a source of water for a withdrawal registered under G.S. 143-215.22H in response to different variables, conditions, and scenarios. The model shall specifically be designed to predict the places, times, frequencies, and intervals at which any of the following may occur:

1. Yield may be inadequate to meet all needs.

2. Yield may be inadequate to meet all essential water uses.

3. Ecological flow may be adversely affected.

c. Be based solely on data that is of public record and open to public review and comment.

(4) Ecological flow. - The Department shall characterize the ecology in the different river basins and identify the flow necessary to maintain ecological integrity. The Department shall create a Science Advisory Board to assist the Department in characterizing the natural ecology and identifying the flow requirements. The Science Advisory Board shall include representatives from the Divisions of Water Resources and Water Quality of the Department, the North Carolina Wildlife Resources Commission, the North Carolina Marine Fisheries Commission, and the Natural Heritage Program. The Department shall also invite participation by the United States Fish and Wildlife Service; the National Marine Fisheries Service; representatives of organizations representing agriculture, forestry, manufacturing, electric public utilities, and local governments, with expertise in aquatic ecology and habitat; and other individuals or organizations with expertise in aquatic ecology and habitat. The Department shall ask the

Science Advisory Board to review any report or study submitted to the Department for consideration that is relevant to characterizing the ecology of the different river basins and identifying flow requirements for maintenance of ecological integrity. The Department shall consider such other information, including site specific analyses, that either the Board or the Department considers relevant to determining ecological flow requirements.

(5) Interstate cooperation. - To the extent practicable, the Department shall work with neighboring states to develop basinwide hydrologic models for each river basin shared by North Carolina and another state.

(6) Approval and modification of hydrologic models. -

a. Upon completion of a hydrologic model, the Department shall:

1. Submit the model to the Commission for approval.

2. Publish in the North Carolina Register notice of its recommendation that the Commission approve the model and of a 60-day period for providing comment on the model.

3. Provide electronic notice to persons who have requested electronic notice of the notice published in the North Carolina Register.

b. Upon receipt of a hydrologic model, the Commission shall:

1. Receive comment on the model for the 60-day period noticed in the North Carolina Register.

2. Act on the model following the 60-day comment period.

c. The Department shall submit any significant modification to an approved hydrologic model to the Commission for review and approval under the process used for initial approval of the model.

d. A hydrologic model is not a rule, and Article 2A of Chapter 150B of the General Statutes does not apply to the development of a hydrologic model.

(7) Existing hydrologic models. - The Department shall not develop a hydrologic model for a river basin for which a hydrologic model has already been developed by a person or entity other than the Department, if the Department determines that the hydrologic model meets the requirements of this subsection. The Department may adopt a hydrologic model that has been developed by another person or entity that meets the requirements of this subsection in lieu of developing a hydrologic model as required by this subsection. The Department may make any modifications or additions to a hydrologic model developed by another person or entity that are necessary to meet the requirements of this subsection.

(8) Construction of subsection. - Nothing in this subsection shall be construed to vary any existing, or impose any additional regulatory requirements, related to water quality or water resources.

(9) Report. - The Department shall report to the Environmental Review Commission on the development of basinwide hydrologic models no later than November 1, of each year."

SECTION 3. The first report required by G.S. 143-355(o), as enacted by Section 2 of this act, is due no later than November 1, 2011.

SECTION 4. This act is effective when it becomes law.

In the General Assembly read three times and ratified this the 8th day of July, 2010.

s/ Walter H. Dalton
President of the Senate

s/ Joe Hackney
Speaker of the House of Representatives

s/ Beverly E. Perdue
Governor

Approved 1:52 p.m. this 22nd day of July, 2010

APPENDIX B – NC Ecological Flows Science Advisory Board Members and Other Contributors

Ecological Flows Science Advisory Board Members

1. **Academic Research**
   Amy Pickle, Nicolas Institute for Environmental Policy Solutions, Duke University

2. **Agriculture**
   Dr. Jeff Hinshaw, NC State University
   Alternate – David Williams, NC Division of Soil and Water Conservation

3. **Electric Public Utilities**
   Hugh Barwick, Duke Energy Carolinas
   Alternate – Thomas Thompson, Duke Energy Carolinas

4. **Environmental Non-Governmental Organizations**
   Sam Pearsall, Environmental Defense Fund
   Alternate – Rebecca Benner, The Nature Conservancy

5. **Local Governments**
   Linda Diebolt, Hazen & Sawyer
   Alternate – Rusty Rozzelle, Mecklenburg County Land Use and Environmental Services

6. **NC American Water Works Association (AWWA-WEA)**
   Jaime Henkels Robinson, CH2M HILL

7. **NC Division of Water Resources (DWR)**
   Fred Tarver
   Alternate – Ian McMillan

8. **NC Division of Water Quality (DWQ)** integrated into NC DWR (Aug 2013)
   No representation for remaining meetings

9. **NC Environmental Management Commission (EMC)**
   No representation as of Aug 2013

10. **NC Forestry Association (NCFA)**
    Bill Swartley, Forestry Non-Point Source Branch, NC Forest Service – Department of Agriculture & Consumer Services
    Alternates – Peter Caldwell, USDA Forest Service & Tom Gerow, NC Forest Service - Department of Agriculture & Consumer Services

11. **NC Natural Heritage Program (NHP)**
    Judy Ratcliffe

12. **NC Marine Fisheries Commission (MFC)**
    Dr. Bob Christian, East Carolina University
    Alternate – Kevin Hart, NC Division of Coastal Management

13. **NC Wildlife Resources Commission (WRC)**
    Chris Goudreau
    Alternate – Vann Stancil

14. **US Geological Survey (USGS)**
    Tom Cuffney, USGS - Raleigh
    Alternate – Holly Weyers, USGS- Raleigh

15. **US Fish and Wildlife Service (USFWS)**
    Mark Cantrell, Asheville Field Office
    Alternate – Sarah McRae, Raleigh Field Office

16. **US National Marine Fisheries Service (NMFS)**
    Fritz Rohde

A list of the NC Ecological Flows Science Advisory Board members and alternates who have served in the following capacities but are no longer serving or no longer serving in these roles for various reasons follows. These members are listed here to recognize their contributions:

- Jessi Baker, NC Division of Marine Fisheries (Alternate to Dr. Bob Christian, East Carolina University)
- Donnie Brewer, Environmental Management Commission – Water Quality and Water Allocation Committees
- Cat Burns, The Nature Conservancy (Alternate to Dr. Sam Pearsall, Environmental Defense Fund)
- Scott Chappell, NC Division of Marine Fisheries (Alternate to Dr. Bob Christian, East Carolina University)
- Vernon Cox, NC Dept of Agriculture and Consumer Services (Alternate to Dr. Jeff Hinshaw, NC State University)
- John Crutchfield, Progress Energy Carolinas
- Jim Mead, NC Division of Water Resources
- Amy Pickle, Environmental Management Commission – Water Quality and Water Allocation Committees
- Steve Reed, NC Division of Water Resources (Alternate to Jim Mead, Division of Water Resources)
- Arlene Roman, City of Gastonia (Alternate to Linda Diebolt, Local Governments)
- Jay Sauber, NC Division of Water Quality

EFSAB Working Groups

To further investigate certain topics outside the scheduled meetings of the EFSAB, ad hoc working groups were formed. The EFSAB determined that these topics were worthy of further investigation beyond the scheduled meetings. Another benefit of the working groups was the involvement of outside subject matter experts, such as was accomplished with the formation of the Coastal Ecological Flows Working Group. Each group then reported its findings during the scheduled meetings of the EFSAB; their findings and recommendations are captured in the meeting summaries. Writing teams developed and proposed sections of the EFSAB report to the board in order to ensure a comprehensive and complete report to the NC Division of Water Resources. These working groups and their members are listed here to recognize their contributions.

Ecological Flows Science Advisory Board Report Writing Teams

- Mark Cantrell, US Fish & Wildlife Service
- Bob Christian, East Carolina University
- Thomas Cuffney, US Geological Survey
- Linda Diebolt, Hazen & Sawyer
- Chris Goudreau, NC Wildlife Resources Commission
- Jeff Hinshaw, NC State University
- Sarah McRae, US Fish & Wildlife Service
- Jim Mead, Environmental Defense Fund
- Sam Pearsall, Environmental Defense Fund
- Amy Pickle, Nicolas Institute for Environmental Policy Solutions, Duke University
- Judy Ratcliffe, NC Natural Heritage Program
- Jaime Robinson, NC American Water Works Association
- Fred Tarver, NC Division of Water Resources
- Tom Thompson, Duke Energy Carolinas

Ad Hoc Research Water Coordination Group

- Thomas Cuffney, US Geological Service
- Mary Davis, Southeast Aquatic Resources Partnership
- Robert Dykes, RTI International
- Michele Cutrofello Eddy, RTI International
- Chris Goudreau, NC Wildlife Resources Commission
- Phillip Jones, RTI International
- Ian McMillan, NC Division of Water Resources
- Jim Mead, EDF Volunteer
- Rua Mordecai, SALCC
- Lauren Patterson, RTI International
- Sam Pearsall, Environmental Defense Fund
- Jennifer Phelan, RTI International
- Fred Tarver, NC Division of Water Resources

Coastal Ecological Flows Working Group

- Bob Christian, East Carolina University, Chair
- Eban Bean, East Carolina University
- Dean Carpenter, Albemarle-Pamlico National Estuary Partnership
- Scott Ensign, AquACo
- Mike Griffin, East Carolina University
- Kevin Hart, NC Division of Coastal Management
- Mike O'Driscoll, East Carolina University
- Mike Piehler, University of NC Institute of Marine Science
- Judy Ratcliffe, Natural Heritage Program
- Fritz Rohde, National Oceanic and Atmospheric Administration
- Bennett Wynne, NC Wildlife Resources Commission

Threatened and Endangered Species Working Group

- Mark Cantrell, US Fish & Wildlife Service
- Chris Goudreau, NC Wildlife Resources Commission
- Sarah McRae, US Fish & Wildlife Service
- Judy Ratcliffe, NC Natural Heritage Program

Guest speakers

Experts on various topics contributed their time to help the EFSAB learn about ecological flows science. The following people provided educational presentations to the EFSAB at their meetings.

- Mark Anderson, The Nature Conservancy
- Bob Christian, East Carolina University
- Tom Cuffney, US Geologic Survey
- Michelle Eddy, RTI International
- Mary Davis, Southern Instream Flow Network
- Robert Dykes, RTI International
- Tom Fransen, NC Division of Water Resources
- Mary Freeman, USGS Patuxent Wildlife Research Center
- Chris Goudreau, NC Wildlife Resources Commission
- Philip Jones, RTI International
- Jim Mead, NC Division of Water Resources
- Kimberly Meitzen, The Nature Conservancy
- Brian McCrodden, Hydrologics
- Thomas Payne, Normandeau Associates
- Sam Pearsall, Environmental Defense Fund
- Jennifer Phelan, RTI International
- Fred Tarver, NC Division of Water Resources
- Ty Ziegler, P.E., HDR/DTA

Facilitation Team

A facilitation team, administered by the Natural Resources Leadership Institute, convened in October 2010. Based on the charter of the EFSAB and guidance from the board, the facilitation team managed the meetings of the EFSAB and provided project support to the board and DWR.

- Mary Lou Addor, EdD, NC State University Cooperative Extension – Natural Resources Leadership Institute
- Christy Perrin, NC University Cooperative Extension – Watershed Education for Communities and Officials
- Nancy Sharpless, Natural Resources Leadership Institute

Recognition of a former facilitation team member for his earlier contributions to the process (Oct 2010 – Aug 2012).

- Patrick Beggs, NC University Cooperative Extension

APPENDIX C – Recommendations for Establishing Ecological Flows in Coastal Waterways

Membership of Coastal Ecological Flows Working Group (CEFWG)

Bob Christian, ECU, chair
Eban Bean, ECU
Dean Carpenter, APNEP
Scott Ensign, AquACo
Mike Griffin, ECU
Kevin Hart, NC DMF
Mike O'Driscoll, ECU
Mike Piehler, UNC IMS
Judy Ratcliffe, Natural Heritage
Fritz Rohde, NOAA
Bennett Wynne, NC Wildlife Resources

(We refer the reader to more detailed summaries of coastal ecological flows activities as part of the EFSAB minutes located on the NC Division of Water Resources website.)

Summary

The low elevation, flat terrain and proximity to tidal, saline waters combine to prevent the use of current hydrologic models in the coastal plain. Different approaches to ecological flows from those described are required, although we lack detailed understanding to provide specific protocols for this region. A more general framework is recommended that categorizes coastal plain streams and identifies four ecological flow approaches to be considered based on stream category. The approaches include extension of the state-wide flow-by criteria; condition of habitat, primarily for anadromous fish; downstream salinity; and overbank flow. Each stream category may be subjected to more than one, but not all, approach. We propose that agencies and organizations within and outside of DENR form a joint committee to further develop this framework.

Uniqueness of coastal ecosystems with respect to ecological flows

Progressing from the piedmont to the coast, streams and rivers become more distinct from those in other regions of the state based primarily on their (1) hydrogeomorphology and hydrodynamics, (2) ecology, and (3) human modifications. Key hydrogeomorphic and hydrodynamic features arise from the flat terrain, low elevation, and tidal influence. Flat terrain and low elevation result in the inundation of extensive riparian swamps, while tidal influence disconnects watershed runoff from being the sole factor affecting river stage. Tides influence coastal rivers far upstream from the saline estuary resulting in tidal freshwater reaches whose hydrology is fundamentally different from rivers in the Piedmont and Mountain regions. Tides may be dominated by astronomical conditions or wind with the latter being more important in the enclosed sounds of the Northeast. These factors result in the potential disconnect between stage and flow and the strong link between flow and water quality (i.e., salinity and dissolved oxygen concentration). Modeling approaches used for the rest of the state for ecological flows do not apply in some coastal plain streams. In addition ground water and surface water are more intimately connected than farther inland. Ecology of coastal waterways includes communities highly influenced by nekton that spend much of their life history within estuarine and ocean waters. Also, submerged aquatic vegetation and riparian wetland trees are integral parts of the ecosystem as foundation species. Finally, current and historical industries have altered the hydrology and ecology of the region. Wetlands have been replaced by linear drainage ways for agricultural production, while more recent desalinization and mining have discharged concentrated brine and depleted groundwater levels, respectively. In summary, the combination of these factors necessitates different approaches to modeling ecological flows than are being used in other regions of the state.

Objectives of Coastal Ecological Flows Working Group (CEFWG)

The overall objective of the CEFWG was to assess the general ability to establish an ecological flows approach for coastal streams, recognizing that a formal recommendation of an approach was unlikely. Rather, the CEFWG has provided a framework for establishing an ecological flows approach. The following summarizes the steps to meet the objective:

- Assess applicability of previous coastal work
    - Other states
    - Greenville Study
- Develop stream typology
- Advance spatial modeling and mapping
- Establish relevant ecological and biological dependencies on flow
- Develop frameworks for potential coastal ecological flows criteria and protocols if possible
- Identify factors limiting ecological flows protocols and needed research within coastal systems

Details are provided in the presentation summary at the EFSAB meeting on July 17, 2013.

Stream typology (led by Scott Ensign)

The coastal plain river network exists with gradients of slope, elevation, influences of tides and seawater intrusion, and degree of human alteration. A stream typology was considered necessary to incorporate recognition of these gradients into ecological flows decision making. The typology in Figure 1 was established as a simplification of a more complex one. It is used to classify reaches under consideration for water flow modifications. The typology identifies several major classification factors: origin, slope or gradient, and wind or tidal influence on stage. These factors are presented as a decision tree that has been used to identify approaches to ecological flows assessment. It should be stressed, however, that there may be no clear demarcation between one category and another, but rather a continuum of influences from the different factors.

This typology highlights two important features of coastal plain rivers. First, ecological flow models based on stage-habitat relationships cannot be used in tidal freshwater rivers. Instead of controlling river stage, discharge emanating from upstream primary controls the upstream intrusion of saltwater. Therefore, ecological flow modeling in tidal freshwater rivers should focus on the effects of flow modification on saltwater intrusion, not on flow affecting the availability of submerged habitat within the channel.

Second, stage-habitat relationships like those used in other regions of the state may be modified for use in the non-tidal coastal plain rivers. However, unlike the models used in other regions, it is necessary to account for the habitat provided by riparian wetlands. Riparian wetlands and swamps occupy a large portion of the coastal plain, are inundated for long period of the year, are highly connected with the hydrology of the channel, and are critical to the ecology of coastal plain rivers.

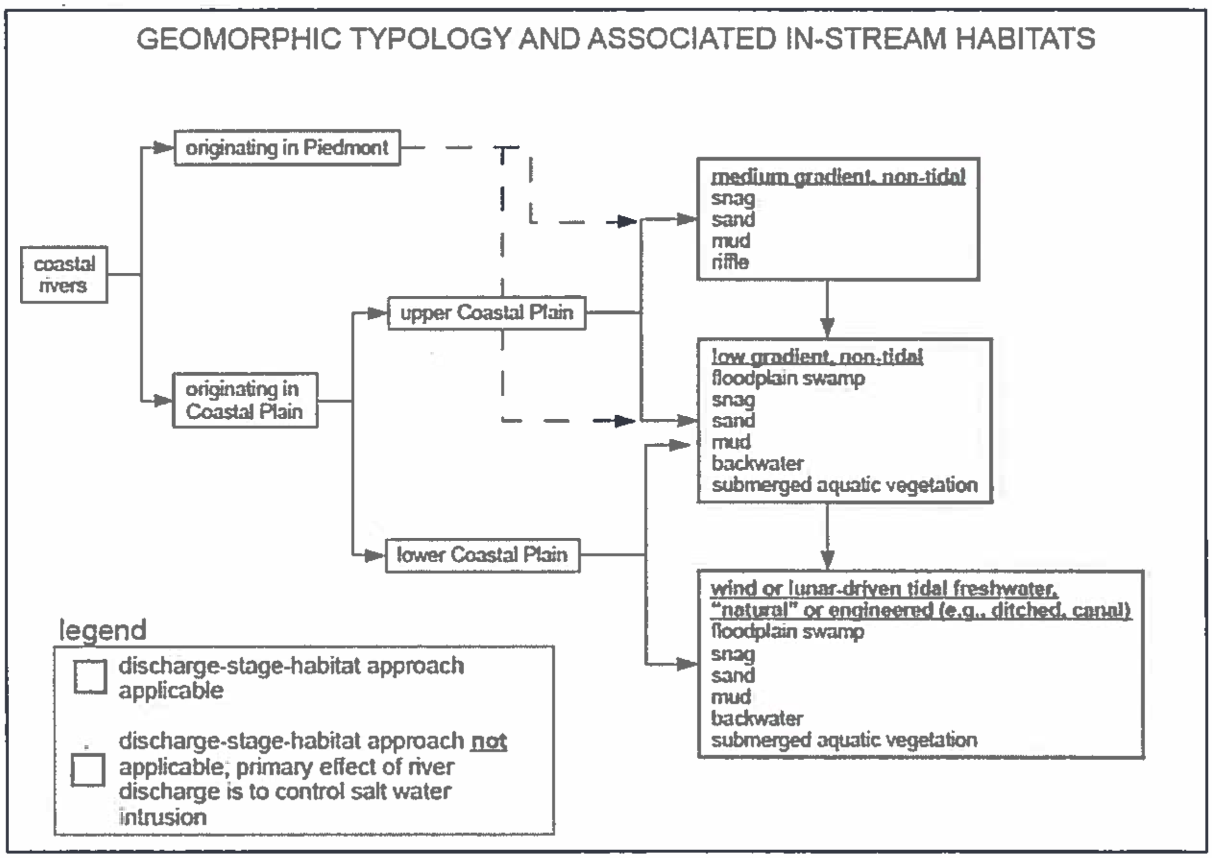

Figure 1. Typology of coastal streams proposed for Coastal Ecological Flows approach decision making.

Spatial modeling and mapping (led by Mike Griffin and Eban Bean)

An initial effort was made to map the typology and other characteristics of the coastal plain and its waterways. Existing data sources were researched and integrated to evaluate the accuracy, relevancy, and applicability for coastal waterway classifications. Key characteristics mapped were (1) the position of the upper and lower coastal plain, (2) origin of waterways, (3) slope categorization, (4) region of tidal influence, and (4) extent of the salt and freshwater interface. A summary map is provided (Figure 2), representing the combination of key features.

Key features were addressed based on the typology shown in Figure 1. The upper and lower coastal plain were initially divided by the Suffolk Scarp (Altor et al. 2005). However, this separation was considered to be of less importance to ecological flows than initially proposed. Mapping was done without this distinction. Waterway origins were manually digitized based on the western boundary of the Coastal plain (Fenneman and Johnson 1946). Stream slopes were determined using USGS 30m resolution digital elevation models (Gesch 2007, Gesch et al. 2002), a stream dataset provided by Kimberly Meitzen of the Nature Conservancy. The slopes varied over several orders of magnitude. A potential threshold between low and medium slope was set at 2.5 mm/m. This threshold places most medium slope streams in the Sand Hills, upper coastal plain, Cape Fear watershed and some tributary streams. The region of tidal influence was designated to be all streams below 1 m in elevation. This threshold appears to generally conform to observations on the Roanoke by Stanley Riggs and Dorothea Ames. The extent of the salt and freshwater interface was estimated by waters classified by the former NC Division of Water Quality (NCDWQ) to be "saltwater" (SA, SB, and SC). Note that the chosen thresholds are proposed to initiate further discussion and consideration.

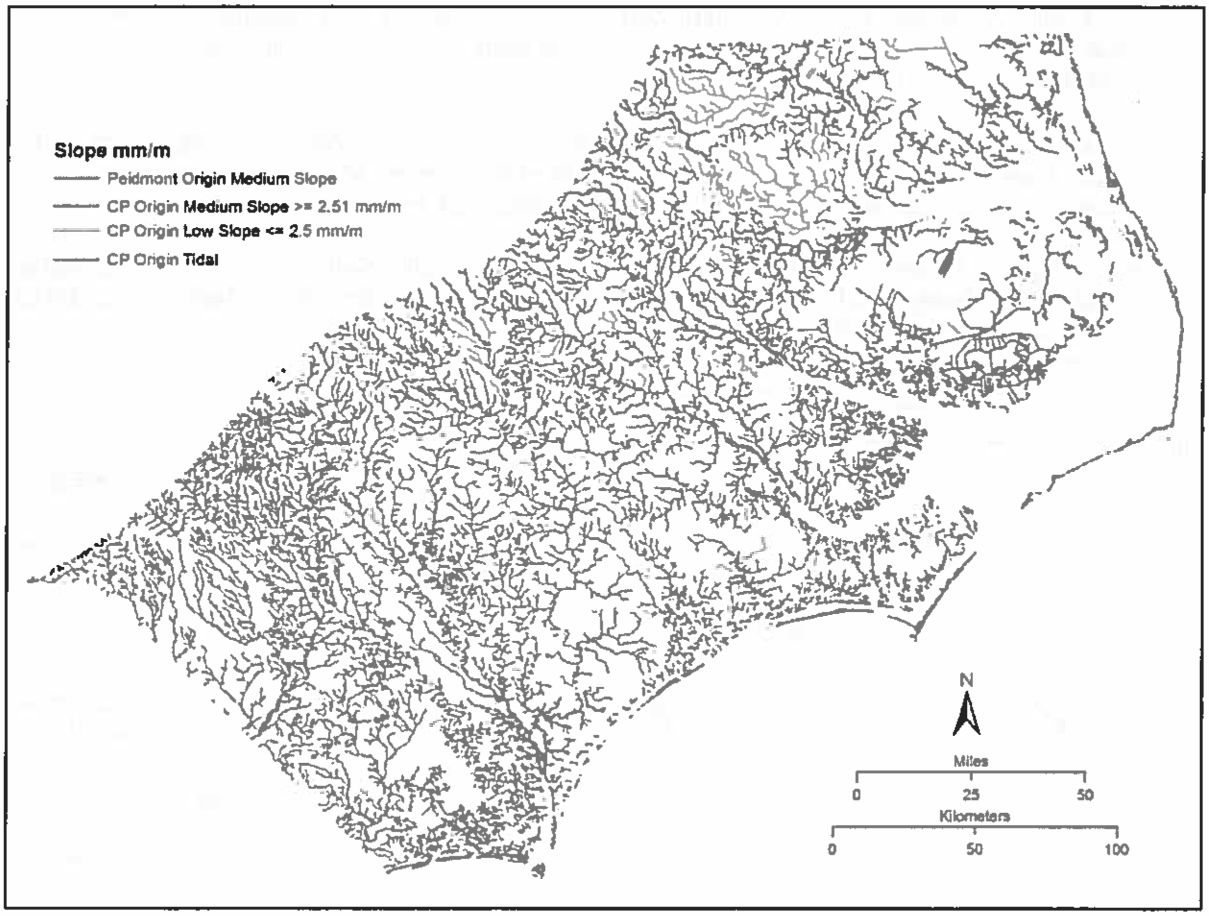

Figure 2. Summary map of key features for consideration of coastal ecological flows.

Relevant ecological and biological dependencies on flow

The CEFWG considered the aquatic communities and ecosystems of the coastal plain and focused attention on two major assemblages: nekton and plant, foundation species. Nekton were characterized as anadromous, catadromous, estuarine or resident species. The former two migrate and spawn in freshwater or the ocean, respectively. The final group tends to grow and develop in the same general area.

Of particular interest are the anadromous fish species. These are ecologically and economically important. Many of these species are important to the food web, acting as key links to primary production or as top predators. Both commercial and recreational fisheries are dependent on some of these species. A large database for them exists within the state as a result. Furthermore, habitat suitability models are available for most species. One critical aspect of habitat is flow. Flow is important to fish spawning and for the times of larval and juvenile growth and development. During these times, flow helps establish the position of the salt wedge and the extent of the freshwater habitat. Dissolved oxygen is another important aspect of habitat suitability related to flow. The Coastal Habitat Protection Plan (CHPP, Deaton et al. 2010) of the NC Division of Marine Fisheries (DMF) identifies some of these factors for specific anadromous fish species (Table 1 from Deaton et al. 2010). Other studies and environmental management actions concern flow requirements for these species. For example flow relations to habitat suitability for the Roanoke River have been established and incorporated into its environmental management.

Anadromous species range across a wide geographic area from conception to adulthood and spawning. Resident species have a narrower range of existence. Many species tend to reside in the lower coastal plain and specifically within the wind/tidal influenced waterways.

Table 1. Physical spawning (adult) and egg development requirements for resident freshwater and anadromous fishes inhabiting coastal North Carolina [Reproduced from Deaton et al. 2010]. [S] = Suitable and [O] = Optimum.

Species	Salinity (ppt)		Temperature (C)		Dissolved oxygen (mg/l)		Flow (cm/s)	Other parameters
	Adult	Spawn/ Egg	Adult	Spawn/ Egg	Adult	Spawn/ Egg	Spawning	Spawn/Egg
Alewife	[S] 0-5	[S] 0-5 [O] 0-2		[S] 11-28 [O] 17-21	[S] ≥3.6	[S] >4	[O] slow current	[S] suspended solids <1000 mg/l
American shad	[S] 0-18	[S] 0-18	[S] 10-30	[S] 13-26	[S] >5		[S] 30-90	
Blueback herring	[S] 0-5	[S] 0-22 [O] 0-2		[S] 14-26 [O] 20-24	[S] >5		[O] strong current	[S] suspended solids <1000 mg/l
Striped bass	[S] 0-5	[S] 0.5-10	[S] 20-22	[S] 12-24 [O] 18-22	[S] >5		[S] 30.5-500 [O] 100-200	
Yellow perch	[S] 0-13	[S] 0-2	[S] 6-30		[S] >5			[S] suspended solids <1000 mg/l
White perch	[S] 5-18	[S] 0-2	[S] 10-30	[S] 12-20	[S] >5			[S] suspended solids <100 mg/l
Sturgeon, Atlantic	[S] 0- >30	[S] 0-5	[S] 0- >30	[S] 12-20				
Sturgeon, Shortnose	[S] 0- >30	[S] 0-5	[S] 0- >30	[S] 5-15				

Riparian wetlands are an integral part of the aquatic ecosystems of the coastal plain. Overbank flow into these wetlands provides water and nutrients to the forests and marshes, but extended flooding in summer can deplete dissolved oxygen that stresses organisms in the wetlands. Swamps dominate the freshwater riparian wetlands and serve as nursery areas and habitat for a variety of aquatic invertebrates, finfish, and birds. Trees act as foundation species for these ecosystems by providing key habitat characteristics of shade, soil stability, and evapotranspiration.

Some coastal plain streams possess submerged aquatic vegetation that also act as foundation species. These species provide habitat for its community and stabilize sediment. The position and extent of these species is flow dependent, in part because of the flow controls the upstream extent of salinity intrusion, and thus alters the habitat requirements for submerged species.

The aforementioned assemblages of organisms provide links between flow and ecological integrity for ecological flow assessments. Individual categories of streams listed in Figure 1 can be expected to be associated with different assemblages (Table 2). Anadromous fish are an important component of the ecosystems of most categories. Plant foundation species are important in low gradient and wind/tidal influenced systems. Resident species of nekton may be another key to ecological flows of wind/tidal influenced systems. The assemblages at this scale are the same for low gradient streams within both the lower and upper coastal plain. Therefore these two categories were merged for later considerations.

Table 2. Link between waterway category and key assemblage that could be used for ecological flow assessment.

Origin	Slope	Assemblage: Anadromous Fish	Assemblage: Resident Fish	Assemblage: Vegetation (Foundation species)
Piedmont	Medium gradient	X		
Upper Coastal Plain	Medium gradient	X		
Upper Coastal Plain	Low gradient	X		X
Lower Coastal Plain	Low gradient	X		X
Lower Coastal Plain	Wind or tidal driven flow		X	X

Framework for potential coastal ecological flows criteria and protocols

It is quite evident that assessing ecological flows within the coastal plain is problematic and requires multiple approaches and approaches beyond those available for the piedmont and mountains. We do not have the knowledge at this time to identify quantitatively specific approaches. Rather we propose a framework that includes three potential directions for which quantitative approaches could be established. This framework is based on the relationship between flow, stage and salinity – all of which relate to habitat and ecosystem functions. Stage depends less on gradient related flow with lower elevation and proximity to the coast. Within stream habitat, volume depends on both stage and flow. Riparian, wetland habitat depends on stage and hence overbank flow. Position of salinity and extent of freshwater along a river depend on both flow and stage. These factors have been integrated into 4 ecological determinants from which assessment approaches can be established: (1) extension of whatever approaches endorsed by the EFSAB for piedmont streams, (2) direct discharge/habitat relationships based on CHPP and related guidelines, (3) position of a prescribed salinity or amount of salinity at a prescribed position, and (4) pattern of overbank flow. These are associated with the different waterway categories in Table 3.

Table 3. Categories of waterways within the coastal plain and relevant ecological flows determinants.

Origin	Slope	EF determinant			
		EFSAB extension	Discharge & Habitat	Downstream salinity	Overbank flow
Piedmont	Medium gradient	X	X	X	
Coastal Plain	Medium gradient	X	X	X	
Coastal Plain	Low gradient		X	X	X
Coastal Plain	Wind or tidal driven flow			X	X

Ecological flow relationships as proposed by the EFSAB, similar to those proposed for other regions, may be used where discharge and stage are still closely correlated. Water level stations exist within the coastal plain below modeled reaches of streams with piedmont reaches. These water levels could be correlated with the upstream or nearby flows from gage stations. When correlation meets some criteria of pattern similarity, regression can be used to extend known flows to ungaged reaches.

Flow requirements and recommendations for the viability of living aquatic resources have been developed for eastern North Carolina and for specific river basins. The NC DMF has developed the CHPP based on the concept of protecting habitat for protection of living marine resources, especially fish and shell fish. The fish and shell fish of concern include those discussed here. This approach has goals similar to the efforts of the EFSAB. The DMF should be directly engaged in establishing an approach based on CHPP and other environmental management plans. This action should also include plans to protect threatened and endangered species.

Salinity is a key water quality factor dependent on flow. Organisms have different physiological tolerances and dependencies for salinity that may vary with life stage. These in turn affect reproductive, developmental and other ecological success. Further, salinity distribution is linked to the potential for low dissolved oxygen conditions, especially in bottom waters. Affected organisms include both animals and plants. Foundation and keystone species can be affected. Either position of a prescribed salinity or the salinity at a prescribed position has been used by other states to index ecological flows. A recent study on the effects of future water withdrawals in Greenville, NC, used salinity within the Tar River as its indicator of effect. The study should provide insight into how this factor could be used for assessing ecological flow effects.

Overbank flow is dependent on stage with varying dependence on discharge associated with location and elevation of a reach. Riparian, freshwater wetlands are often inundated during colder months and dry or infrequently flooded during warner months. This pattern is needed to maintain community structure and ecosystem function of these wetlands. Blackwater streams from high dissolved organic matter concentrations and low DO flushed from wetlands, along with slow velocities, drive unique characteristics. Ecological flows within the coastal plain thus should address the ecological integrity of these wetlands more than what might be expected for the piedmont or mountains.

Process for moving forward

The framework presented here advances the assessment of ecological flows within the coastal plain but not to the extent of that in other regions. It represents a way forward, but requires further understanding of the relationships that control ecological flows and institution of assessment approaches. These can be provided by the resources of North Carolina. No one program within the state has the expertise or resources to fully advance and refine the framework. It will take coordination and cooperation of the agencies within DENR and the research community.

Several agencies within DENR can contribute expertise and effort to the cause. The Albemarle Pamlico National Estuary Program (APNEP) has ecological flows as a primary mission within its Comprehensive Conservation and Management Plan (2012). Its research director, Dean Carpenter, participated in the CEFWG and APNEP is prepared to further the work of the working group, at least for the watersheds of the Albemarle and Pamlico Sounds. The DMF and NC Wildlife Resources have expertise on the key species and habitats of coastal North Carolina. CHPP, fisheries management plans and habitat suitability models should be applied to the ecological flows. The expertise of what were the Division of Water Quality and Division of Water Resources is essential to extending both ecological condition of coastal ecosystems and the hydrological modeling. The Ecosystem Enhancement Program (EEP) also would have interest and relevant expertise. The Water Resources Research Institute (WRRI) and Sea Grant Program (SG) at NC State University provide a connection to the research community. All of these agencies have an interest and stake in ecological flows within the coastal plain that go beyond the immediate legislative needs directing the EFSAB.

Representatives of state agencies and others should meet to determine (1) general goals and objectives, (2) their needs within this topic, (3) expertise and resources available from each, and (4) a plan to move to achieve both general and individual goals. Once these agencies can establish their aggregated objectives and general approach, other organizations can be invited to participate. Other contributors should include various willing partners who participated in the EFSAB (e.g., industry and agricultural groups, federal and local government entities, environmental groups). This should include RTI, which did not have membership on the Board but contributed greatly. Initial leadership should come from someone associated with EFSAB activities, but once a path forward is determined, this requirement may not be necessary.

Coincidental to this activity should be the stimulation of research directed toward ecological flows within the coastal plain. WRRI and SG would be the likely sources of funds for this action, but other agencies may have more directed funding opportunities. Below is a list of research needs developed by the CEFWG and EFSAB.

Suggested research within coastal systems

Considerable information is needed before a quantitative approach can be established for the coastal plain. Below is a list of research or development that would benefit this effort.

1. Determine correspondence of known discharge patterns with nearby coastal plain stream flow patterns.
2. Determine the upper-most extent of tidal influence across coastal plain.
3. Evaluate juvenile abundance indices vs. flow and salinity/conductivity.
4. Map salinity distribution across coastal plain.
5. Quantify stream typology classes.
6. Evaluate Roanoke slabshell and other mussel distributions and abundance as informative of salinity and flow patterns.

7. Determine hydrologic metrics and characteristics of coastal streams.

8. Determine reference flow regimes for each river basin.

9. Assess the balance of withdrawals from and discharges to coastal streams.

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APPENDIX D – Flow Alteration – Biological Response Relationships to Support the Determination of Ecological Flows in North Carolina

FLOW ALTERATION 2 NIOLOGIOAL RESPONSE RELATIONSHIPS TO SUPPORT THE DETERMINATION OF EOOLOGIOAL FLOWS IN NORTH OAROLINA

A Final Report prepared for Environmental Defense Fund, North Carolina Department of Environment and Natural Resources, and North Carolina Wildlife Resources Commission

By RTI International and U.S. Geological Survey

Contents

Figures

Fasselt, Veronica

From: Able, Tony
Sent: Tuesday, March 18, 2014 9:07 AM
To: Fasselt, Veronica
Subject: FW: N.C. Department of Environment and Natural Resources announces new Office of Land and Water Stewardship

Tony Able, PG
Chief, Wetlands Regulatory Section
U.S. Environmental Protection Agency
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Atlanta GA, 30303
phone 404 562 9273
Cell 404 821 9066

From: Evans, Rhonda
Sent: Thursday, November 14, 2013 9:30 AM
To: Derby, Jennifer; Able, Tony
Cc: Katz, Marilyn
Subject: FW: N.C. Department of Environment and Natural Resources announces new Office of Land and Water Stewardship

fyi

From: Crowell, Bill [mailto:bill.crowell@ncdenr.gov]
Sent: Tuesday, November 12, 2013 6:55 PM
To: Carpenter, Dean; Johnson, Jimmy; Smart, Lindsey S; Todd Miller; Tom Allen; Kirk Havens
Cc: Evans, Rhonda; Derby, Jennifer; Mcshane, John; Katz, Marilyn
Subject: FW: N.C. Department of Environment and Natural Resources announces new Office of Land and Water Stewardship

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From: <Kritzer>, Jamie <jamie.kritzer@ncdenr.gov>
Date: Tuesday, November 12, 2013 9:24 AM
Subject: N.C. Department of Environment and Natural Resources announces new Office of Land and Water Stewardship

Pat McCrory, Governor
John E. Skvarla, III, Secretary

N.C. Department of Environment and Natural Resources

Release: Immediate
Date: Nov. 12, 2013

Contact: Jamie Kritzer
Phone: 919-707-8602

N.C. Department of Environment and Natural Resources announces new Office of Land and Water Stewardship

Office will report to Cecilia Holden in the secretary's office

RALEIGH – The N.C. Department of Environment and Natural Resources announced today the formation of the Office of Land and Water Stewardship, which will coordinate the efforts of the Albemarle-Pamlico National Estuary Partnership, the N.C. Clean Water Management Trust Fund, and the N.C. Natural Heritage Stewardship Program. The office will report to Cecilia Holden, special assistant to Secretary Skvarla.

"One of the many ways we protect North Carolina's environment is to act as good stewards of our resources," said John E. Skvarla, secretary of the N.C. Department of Environment and Natural Resources. "So it makes sense to combine our stewardship programs into one office to capitalize on their similar resource needs. Cecilia's experience and expertise will ensure the programs are run as efficiently as possible for the benefit of the environment and our citizens."

Through legislation passed this summer, key provisions of the Natural Heritage Trust Fund's mission were incorporated into the Clean Water Management Trust Fund and the funds themselves were merged.

Holden's business management background has focused on people and project management, data and expenditure analysis, customer satisfaction improvement, and business plan composition. Her career breadth includes 12 years in local and state government positions in North Carolina as well as a decade in the private sector. She earned a bachelor's degree in computer science and business from the University of North Carolina-Wilmington, a Master's of Business Administration degree from Duke University and a certificate in public administration from the University of North Carolina at Chapel Hill.

The Office of Land and Water Stewardship

The Albemarle-Pamlico National Estuary Partnership works to identify, protect and restore the significant resources of the Albemarle-Pamlico estuarine system. It is a cooperative effort jointly sponsored by the N.C. Department of Environment and Natural Resources and the U.S. Environmental Protection Agency, and in partnership with the Virginia Department of Conservation and Recreation. The program area extends across most of the Albemarle-Pamlico watershed, including the Neuse, Tar-Pamlico, Roanoke, Chowan, lower Roanoke, and parts of the White Oak River basins.

The Clean Water Management Trust Fund provides grant assistance to conservation nonprofits, local governments and state agencies across the state for the protection and restoration of surface waters, including drinking water supplies; the protection of significant ecological, cultural and historic sites; and the provision of buffers around bases to protect the state's critical military mission.

The mission of the Natural Heritage Program is to survey natural areas with the goal of finding and documenting locations of rare species and high quality natural communities and sharing that information to support economic development. The Stewardship Program provides monitoring and management of conservation easements and lands held by the N.C. Department of Environment and Natural Resources for stream and wetland mitigation.

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Fasselt, Veronica

From: Evans, Rhonda
Sent: Friday, November 22, 2013 12:31 PM
To: Able, Tony; Derby, Jennifer; Katz, Marilyn
Subject: FW: NC scientists, lawmakers gather in New Bern for ecosystem symposium -

Press on the the APNEP State of the Sounds Symposium Wednesday.

From: Crowell, Bill [mailto:bill.crowell@ncdenr.gov]
Sent: Thursday, November 21, 2013 9:22 AM
To: Evans, Rhonda; Katz, Marilyn; Derby, Jennifer; Carpenter, Dean; Smart, Lindsey S; Johnson, Jimmy
Subject: FW: NC scientists, lawmakers gather in New Bern for ecosystem symposium -

http://coastal.news14.com/content/news/701808/nc-scientists--lawmakers-gather-in-new-bern-for-ecosystem-symposium

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NEWS (/content/news/)

NC scientists, lawmakers gather in New Bern for ecosystem symposium

By: Leland Pinder 11/20/2013 06:27 PM

NEW BERN, N.C. -- Scientists from around the state as well as policy-makers and interested citizens gathered in New Bern Wednesday for an ecosystem symposium.

They're coming together to share ideas and explore scientific developments in environmental restoration and protection. The Albemarle-Pamlico Estuary Partnership hosted the event. They say their work is far reaching.

"Our projects run from the gamut of doing a small project at a school yard to address stormwater and educate people about the importance of habitats and keeping clean water to working with multiple agencies...federal, state government and local groups," said Albemarle-Pamlico Estuary Partnership Director Dr. Bill Crowell.

Dr. Michael Piehler is an associate professor at the UNC Institute of Marine Sciences in Morehead City. He says understanding ecosystems is important because of not only what they do for the environment but because of what they can do for us. For instance, oysters serve many purposes aside from being a tasty seafood treat for humans.

"They regulate water quality, they keep shorelines stable, they retain the features of the environment that are valuable to us from a recreational perspective," said Piehler.

Commercial fisherman David "Clammerhead" Cessna is a partner with the scientific community.

"We're learning faster, better, safer and healthier ways of growing seafood and protecting the environment," said Cessna.

These types of projects and symposiums enable scientists to help consumers get what they want while making sure the environment still gets what it needs.

The Albemarle-Pamlico Estuary Partnership covers waters from the Neuse River Basin all the way up to the Chowan and Pasquotank River Basins into Virginia. Nearly 40 presentations on various topics were given at the symposium.

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Fasselt, Veronica

From:	Able, Tony
Sent:	Tuesday, December 10, 2013 10:16 PM
To:	Derby, Jennifer; Holliman, Daniel; Godfrey, Annie; Evans, Rhonda
Subject:	RE: NOAA Request for Participating in River Herring Conservation Plan

Rhonda and I had discussed this as part of a restoration goal for APNEP.

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From: Derby, Jennifer
Sent: Tuesday, December 10, 2013 10:06 AM
To: Holliman, Daniel; Godfrey, Annie; Able, Tony
Subject: RE: NOAA Request for Participating in River Herring Conservation Plan

Dan – I'm copying Tony Able to see if he has any recommendations– my first thought in HQ's would be the Wetlands Division or Watershed Division (not a fit for Ocean and Coastal group; I don't know Tom Wall – but got below info from website).

- Assessment and Watershed Protection Division
  Tom Wall, Director
  - Phone: 202-564-4179
  - Email: wall.tom@epa.gov

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From: Holliman, Daniel
Sent: Tuesday, December 10, 2013 8:31 AM
To: Godfrey, Annie; Derby, Jennifer; Carter, Bobbi
Cc: Mueller, Heinz; Zimmer, Andrea
Subject: RE: NOAA Request for Participating in River Herring Conservation Plan

Thanks for the input Jennifer and Annie. Do you have any suggestions for contacts at HQ's?

-Dan

From: Godfrey, Annie
Sent: Tuesday, December 10, 2013 6:36 AM
To: Derby, Jennifer; Holliman, Daniel; Carter, Bobbi
Cc: Mueller, Heinz; Zimmer, Andrea
Subject: RE: NOAA Request for Participating in River Herring Conservation Plan

I agree with Jennifer that HQ would be the best entity to coordinate this. However, there are probably folks in our Division that would be interested in it. I'm copying Andrea because Dave Melgaard in her section might be interested. I could check with the WQS group also, if we are going to pursue this at the regional level.

From: Derby, Jennifer
Sent: Monday, December 09, 2013 5:47 PM
To: Holliman, Daniel; Godfrey, Annie; Carter, Bobbi
Cc: Mueller, Heinz
Subject: RE: NOAA Request for Participating in River Herring Conservation Plan

Dan – this has both a national and regional scope – wondering if someone from HQ's has been approached about this? And – might be useful to circulate to the whole Water Division for interest? But I'm wondering if HQ's would be better option for coordinating a workgroup – because multiple regions could be involved.

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From: Holliman, Daniel
Sent: Monday, December 09, 2013 4:41 PM
To: Godfrey, Annie; Derby, Jennifer; Carter, Bobbi
Cc: Mueller, Heinz
Subject: NOAA Request for Participating in River Herring Conservation Plan

Please see attached letter from NOAA Fisheries regarding a request for EPA to participate in an initiative to develop a dynamic conservation plan to help and restore river herring from Canada through Florida. NOAA is looking for participants from state and federal agencies to participate on development of this plan. Do we have anyone that would be interested in participating? If so, let me know before December 13th, 2013 so we can respond accordingly.

If I have missed folks that you think might be interested please forward.

Thanks,
Dan

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Region 4 NEPA: http://www.epa.gov/region4/opm/nepa/index.html